PRODUCT ENGINEERING

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They Dedicate Their Lives To Progress

IN THE BEGINNING of this great era of scientific development and invention, the things to be discovered were comparatively simple to ascertain, when measured by the fund of knowledge, experimental apparatus and money required. This does not detract from the credit due the scientists and inventors who laid the groundwork and provided this civilization with the innumerable things that have added to our material well being, have relieved suffering and have made life more comfortable. interesting and exciting. Fame and glory cannot compensate the pioneers of science and civilization for the sacrifices they made, the hardships they endured and the humiliation to which they were subjected when scorned and derided by a skeptical world. No monuments to them can be great enough.

Sir Isaac Newton, upon being lauded as the most learned man of his time, said, "I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the seashore and diverting myself in now and then finding a smooth pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me." If Newton were living today he would see many of the pebbles with which he had played now serving as rocks in the foundation of our civilization, and only a few smooth pebbles still lying on the sands of the beach. Man must now explore the depths of the ocean of knowledge in his quest for the secrets of nature and to do that requires specialized talents, organized effort, unlimited facilities, time and money—all to a degree that rarely one man is able to possess or command, least of all, a devoted scientist or a philosophical dreamer.

It is quite natural that industry, created by science and invention, now furnishes the wherewithal without which scientific progress would cease or at least stagnate. At first, new things were created faster than industry could make them available to society, which impelled industry to gear itself for an increasingly rapid expansion, a pace that soon outstripped the rate of new developments forthcoming from the efforts of individuals. Industry was thereby forced to realize that its further progress, or perhaps even its survival, required new developments at a rate that lone research workers could not attain. To meet this situation, industry established research laboratories, industrial fellowships at technical universities and independent research institutions, and now contributes to scientific societies and undertakes inter-industrial co-operation for developing new things or new processes or discovering some hitherto unknown law of nature.

With industry supporting science and engineering, organized effort supplanted the lone worker and great laboratories were built and equipped with all the instruments, devices and machinery that research workers could desire. With minds freed of the worries of personal finances, not handicapped by the necessity of cutting experimental costs to the bone and not being compelled to be mindful of time, these creators of the new attacked the secrets of nature with a zeal and effectiveness never surpassed. And Industry flourished.

But in spite of the highly organized state of industrial research, in spite of its vast ramifications and the complexity of its operations, and in spite of the fact that scientific and industrial research now largely owes its continuing existence to Capital and Business, its accomplishments are still, and ever will be, the creation of individuals, men of science and engineering. Cooperative effort, contributions of fellow workers and investigations made possible only by the backing of business, often blot out the individual to whom the credit is due. But be it so or otherwise, it is to men of science and engineering, who have dedicated their lives to progress, that the world owes the innumerable joys and blessings of the civilization we call ours.

ANALYSIS OF VARIANCE

Applying the Method to Industrial Problems

A. G. BROOKS
Western Electric Company

Possible applications of a statistical method, with an explanation of its technique, to types of industrial problems for evaluating the relative effect of causes of variation in products

BEFORE DESCRIBING specific problems to which the analysis of variance method has been applied, a discussion of the method itself and the statistical principles underlying it is not out of place. Mr. Snedecor, in his book "Calculation and Interpretation of Analysis of Variance and Covariance," defines analysis of variance as "a technique for segregating from comparable groups of data the variation traceable to specified sources." Paraphrasing this it might be said that, analysis of variance is a method of breaking down the total variation in a set of data into component variations which can be associated with or traced to definite sources of variation.

A practical example may serve to throw more light on the meaning of analysis of variance than mere definitions could hope to do. Suppose the thickness of ten sheets of phosphor bronze were measured by taking four micrometer readings at random on each sheet. The analysis of variance of these data will show either that the 40 readings are as consistent from sheet to sheet as would have been expected if all had been taken at random from the same sheet, or that they vary more from sheet to sheet than could be ascribed to random fluctuations, indicating that the sheets are probably taken from different sources. With this in mind consider the hypothetical data shown in Table 1, which at a glance shows variation in measurements within sheets as well as from sheet to sheet. Now examine the frequency table shown in Fig. 1, in which for convenience the average of each sheet has been indicated with a horizontal bar to emphasize the variation.

By a well-known theorem of classical statistics, the standard deviation of averages of random samples varies inversely as the square root of the number of observations per sample. This means that the average of random samples of four should vary $1/\sqrt{4}$ or one-half as much as the individual observations in the universe. Neglecting a slight correction which should be made for small sample sizes, this classical theory may be tested out graphically in Fig. 2 as follows:

First, the frequency distributions for the ten sheets are plotted on a scale showing the deviation of each observation from the sheet average. This amounts to shifting or translating the observations on the several sheets to a common level so that their averages fall on the same horizontal line, which, on the scale of deviations, is the "zero deviation line." Next, the sheet averages are plotted on a magnified scale of deviations in which each unit space is $\sqrt{4}$ times or twice as large as the other scale in Fig. 2. The purpose of the magnified scale is to make the scatter or spread of the distribution of averages graphically comparable to the scatter of the individual observations, the factor $\sqrt{4}$ being the theoretical relationship between the standard deviations of the two distributions in this data. Fig. 2 thus affords a more direct graphical comparison than Fig. 1 of the variation "within sheets" and "between sheets."

In Fig. 2, the spread of the distribution of sheet averages appears larger than the spread of the individual observations within sheets, indicating a tendency for the material to vary more from sheet to sheet than within a sheet. The analysis-of-variance technique may be applied to evaluate the significance of these variations from sheet to sheet as compared with the variations within a sheet which a graphical picture such as Fig. 2 brings out geometrically. The analysis of variance is usually calculated directly from the original raw data, thus eliminating the frequency tables in Figs. 1 and 2. In this example the graphical analysis has been purposely included to provide a geometric interpretation of the analysis of Variance of the data. First the analysis of variance shall be calculated from Fig. 2, and later from a method based on the data in Table I it will be shown how the same end result may be obtained.

Compute first the "sum of squares within sheets" which is shown in the second column of Table II. This is merely a total obtained by squaring the deviation of each individual observation

Table I. Thickness Measurements on Phosphor Bronze Sheets

Micrometer Readings in Thousandths of an Inch — 4 Readings per Sheet

	Sheet Number									
Reading	1	2	3	4	5	6	7	8	9	10
1.....	50.3	50.0	51.0	50.4	50.6	50.9	49.5	50.7	49.9	50.3
2.....	50.6	49.7	50.7	49.9	50.8	50.3	49.6	50.3	50.1	49.8
3.....	50.0	49.8	50.3	50.5	50.2	50.5	50.4	51.0	49.6	50.0
4.....	50.7	50.5	50.4	49.6	50.8	50.7	50.1	50.8	50.0	50.7
Sheet average..	50.4	50.0	50.6	50.1	50.6	50.6	49.9	50.7	49.9	50.2

Table II. Analysis of Variance

4 Thickness Readings on Each of 10 Phosphor Bronze Sheets

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Standard Deviation
Within Sheets.....	3.36	30	0.112	0.335
Between Sheets.....	3.60	9	0.400	0.634
Total.....	6.96	39	0.178	0.422

Table III. Computation of Analysis of Variance from Raw Data on thickness of Phosphor Bronze Sheet

	Sheet Number										
	1	2	3	4	5	6	7	8	9	10	
	50.3	50.0	51.0	51.4	50.6	50.9	49.5	50.7	49.9	50.3	
	50.6	49.7	50.7	49.9	50.8	50.3	49.6	50.3	50.1	49.8	Grand total
	50.0	49.8	50.3	50.5	50.2	50.5	50.4	51.0	49.6	50.0	for all
	50.7	50.5	50.4	49.6	50.8	50.7	50.1	50.8	50.0	50.7	10 columns
Total.....	201.6	200.0	202.4	200.4	202.4	202.4	199.6	202.8	199.6	200.8	2,012.0 (A)
Average.....	50.4	50.0	50.6	50.1	50.6	50.6	49.9	50.7	49.9	50.2	50.3 (B)
Total × Average..	10,160.6	10,000.0	10,241.4	10,040.0	10,241.4	10,241.4	9,960.0	10,282.0	9,960.0	10,080.2	101,207.2 (C)
Total of Squares..	10,160.9	10,000.4	10,241.7	10,040.6	10,241.7	10,240.6	9,960.6	10,282.2	9,960.2	10,080.6	101,210.6 (D)

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*
Within Sheets	D − C = 3.36	(Obs. per Sheet − 1) (No. Sheets) = (4 − 1) (10) = 30	0.112
Between Sheets	C − A × B = 3.60	(No. Sheets − 1) = (10 − 1) = 9	0.400
Total	D − A × B = 6.96	(No. Observations − 1) = 40 − 1 = 39	0.178

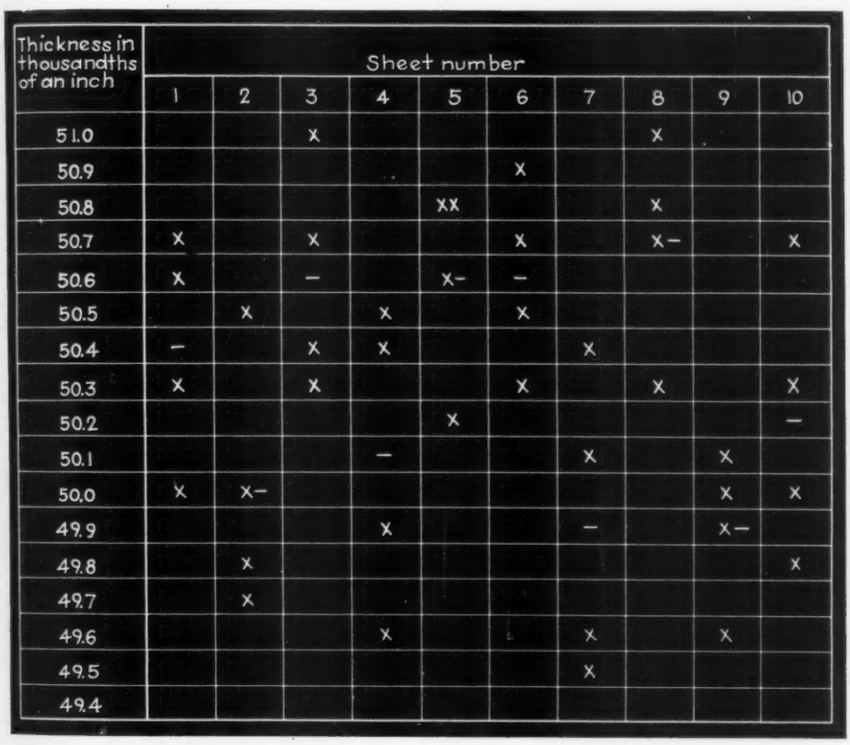


Fig. 1—Frequency of thickness measurements on ten phosphor bronze sheets plotted from the data tabulated in Table I

from its respective sheet average and summing up the squared deviations.

Next compute the "sum of squares between sheets." This is obtained by squaring the deviations of the sheet averages from the grand average for all sheets and multiplying each of these squared deviations by the number of observations per sheet which serves to weight the deviations in accordance with the number of observations on which each average is based. In column two of Table II are shown the "sum of squares between sheets" which are merely the total of these squared deviations.

The "total sum of squares" is equal to the sum of the squared deviations of each observation from the grand average of the sample. The total obtained in this manner has been entered in column two of Table II and it is interesting to note that this total is exactly equal to the sum of the two "sum of squares within sheets and between sheets" previously obtained. This additive property of the sums of squares is the basic mathematical theorem on which Analysis of Variance is founded.

The column in Table II, headed "Degrees of Freedom," introduces an idea somewhat foreign to classical statistical theory. Before the turn of this century, it was customary to estimate the standard deviation of the universe by dividing the sum of the squared deviations from the mean by the number of observations and extracting the square root of this number, without further correction. Theoretically, however, this is not quite correct because values of the standard deviation obtained in this manner will, in the long run, tend to average less than the true standard deviation of the universe. It can be demonstrated mathematically that there is a slight bias inherent in this method. The extent of this bias is appreciable only for small sample sizes, for practical purposes less than about 25. In analysis of variance, the correction for sample size is accomplished by dividing the sum of the squares of the deviations by the number of "degrees of freedom" rather than by the sample size itself.

The degrees of freedom are the number of independent relations on which each sum of squares is calculated. For example, in Table II, the "sum of squares within sheets" is associated with 3 degrees of freedom for each of 10 sheets or 30 degrees of freedom all told, because the deviations of the observations were measured from their sheet averages so that any three of the four deviations on a sheet might be considered independent, the remaining deviation being dependent on the average. Similarly, the "sum of squares between sheets" is associated with 9 degrees of freedom because the deviations of the 10 sheet averages from their grand average consist of 9 independent and one dependent deviation. Finally, the total sum of squares is based on 39 degrees of freedom, representing deviations of all but one of the observations from the grand average. In general, the number of degrees of freedom associated with any particular sum of squares is equal to the number of observations or groups

of observations on which that sum of squares is based, deducting one degree of freedom for each average or other statistical constant which was used in the computation of the deviations.

The column headed "Mean Square" in Table II is obtained by dividing each "sum of squares" by its corresponding "degrees of freedom." The column headed "Standard Deviation" contains the square roots of the mean squares.

With this data it can be seen numerically how the variation from sheet to sheet compares with the variation within a sheet. The mean square "between sheets" is seen to be larger than the mean square "within sheets" and the ratio of the two is 0.400 divided by 0.112 or 3.57. In the table, page 90, in Mr. Snedecor's book "Analysis of Variance," this ratio, based on 9 and 30 degrees of freedom respectively, is found to be significant because the probability is less than 0.01 that the variation between sheets will be as large or larger in random sampling than the observed value. From this it is concluded that the lot contains material manufactured under different sets of conditions.

Before leaving this mathematical example, it would be well to point out a short method of computing the analysis of variance from the raw data. In Table III the original data of Table I is shown together with the computations necessary for setting up the analysis-of-variance table.

The total, average, and sum of squares of the observations are shown at the bottom of each column. Also, the product of the column total times the column average is shown. These figures are summed up for all columns at the right of the chart and the grand average of the sample computed. The product of the grand total times the grand average is subtracted from the total of the squares of individual observations. This difference is the sum of the squared deviations of the individual observations from their grand average and is entered in the analysis-of-variance table as the "total sum of squares." Next, the product of the grand total times the grand average is subtracted from the sum of the products of the column totals times the column averages. The resulting difference is the "sum of squares between sheets" which is entered in the proper column and line of the analysis-of-variance table. Subtracting the "sum of squares between sheets" from the "total sum of squares" gives the "sum of squares within sheets." The latter quantity is often independently calculated to prove a verification check of the other calculations but is not strictly necessary. The degrees of freedom are obtained by inspection of the data as described previously.

A practical problem in the field of quality control to which the analysis-of-variance method has been applied will now be discussed. The problem chosen is illustrative of general types. It is the problem which arises in sampling inspection of determining the best way to distribute a sample to make it representative of material where successive tests on the same piece show considerable variation, making it difficult to reproduce test results. Table IV shows the analysis of variance of 128 measurements of insulation resistance of a certain type of insulating material.

In this problem, instead of two sources of variation as there was in the previous example, there are three sources; namely, the variation in successive tests on the same specimen, variation in the specimens at different locations of the sheet, and variation from sheet to sheet. The analysis-of-variance table may be set up for any number of sources of variation, merely by an extension of the same basic principles involved in the example of phosphor bronze sheets.

In the present problem, analysis of variance shows that the variation between locations within a sheet is significantly greater than the variation within specimens, and also that the variation between sheets is significantly greater than the variation between specimens within a sheet. The practice in the shop had been to take nine readings on a specimen and test correspondingly few sheets. As a result of this study, however, it was recommended that fewer readings be made per specimen and more specimens and more sheets be tested per lot to make the samples more representative of the material.

Deviation of observation from average of sheet	Observations within sheets										Deviation of sheet average from grand average
	1	2	3	4	5	6	7	8	9	10	
+ 0.8											+ 0.4 X
+ 0.7											
+ 0.6											+ 0.3XXX
+ 0.5		X					X			X	
+ 0.4			X	X							+ 0.2
+ 0.3	X			X		X		X			
+ 0.2	X				XX		X		X		+ 0.1 X
+ 0.1			X			X		X	X	X	
0		X			X			X	X		0
− 0.1	X					X					
− 0.2		X	X	X						X	− 0.1X
− 0.3		X	X			X	X		X		
− 0.4	X				X		X	X		X	− 0.2 X
− 0.5				X							
− 0.6											− 0.3 X
− 0.7											
− 0.8											− 0.4 XX

Fig. 2—Frequency of deviations in thousandths of an inch of thickness of phosphor bronze sheets, Table I shows original data

Table IV. Insulation Resistance Measurements of 8 Sheets of Insulating Material

16 Readings per Sheet — 4 Specimens Were Selected from Each Sheet at Different Locations and 4 Readings Were Taken on Each Specimen

ANALYSIS OF VARIANCE

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Standard Deviation
Within Specimens	572.70	96	5.966	2.44
Between Specimens Within a Sheet	874.26	24	36.427	6.04
Between Sheets	2,186.35	7	312.336	17.67
Total	3,633.31	127	28.609	5.35

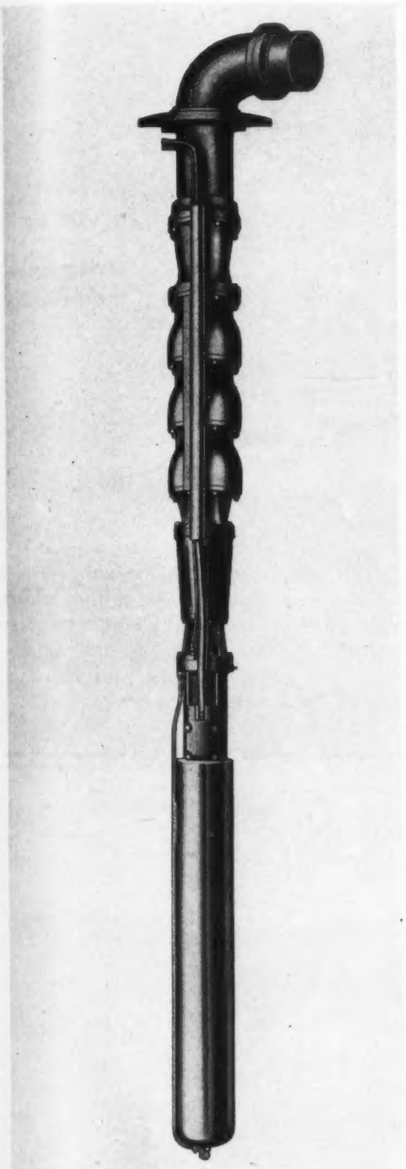
(a) $\frac{\text{Mean Square Between Specimens}}{\text{Mean Square Within Specimens}} = \frac{36.427}{5.966} = 6.10$

(b) $\frac{\text{Mean Square Between Sheets}}{\text{Mean Square Between Specimens}} = \frac{312.336}{36.427} = 8.57$

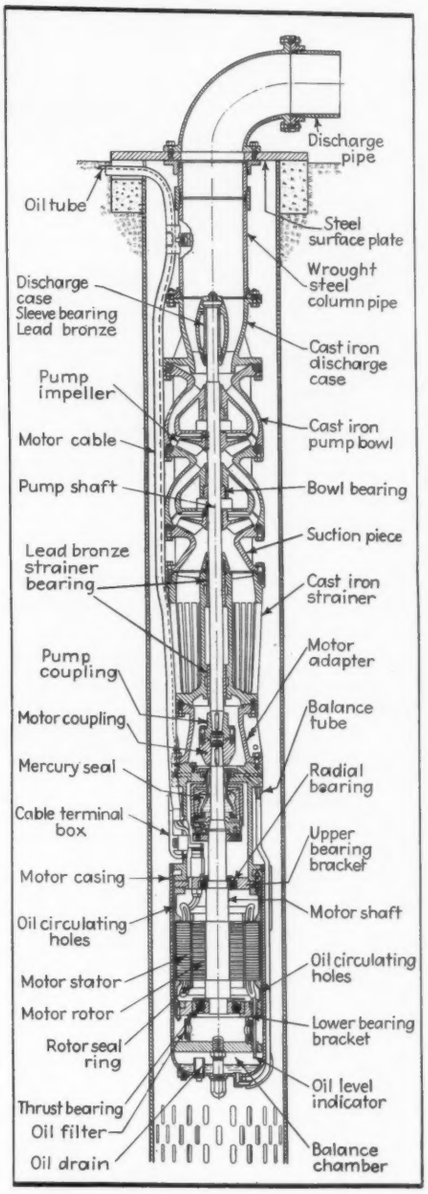
Note: Ratios (a) and (b) are both significant in that the probability of occurrence in random sampling is less than 0.01.

Modern Designs

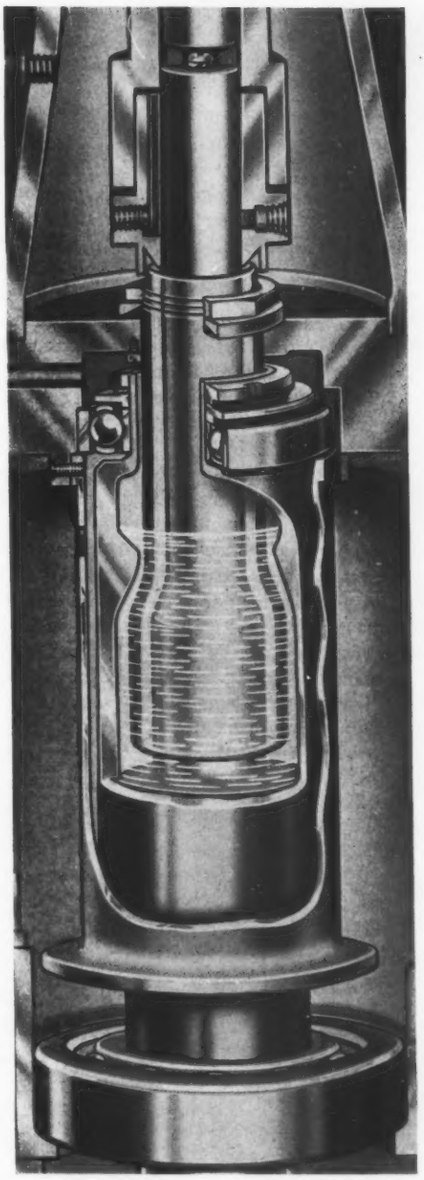
Motor Has Nine-to-One Length-Diameter Ratio



Close-coupling of motor and pump eliminates long shafting, extra bearings and thus adds to pump efficiency in the deep-well design developed by the Byron Jackson Company. Propelling shaft is short and the long, small-diameter motor operates submerged at all times in the well. Electric power is delivered from switch box to the motor through lead covered, steel-armored conductors. Water entering pump flows past motor, cooling it.



Motor is of squirrel-cage induction type, with rotor carried on two bearings—one radial and the other radial-thrust to take weight and hydraulic load; and is totally enclosed in a steel case filled with high dielectric oil. Motor length-diameter ratios are about nine to one; the 100 hp. motor being 88 in. long and 9 in. in diameter. When oil is needed, a relay stops the motor, and oil can be added through the oil tube from the surface.



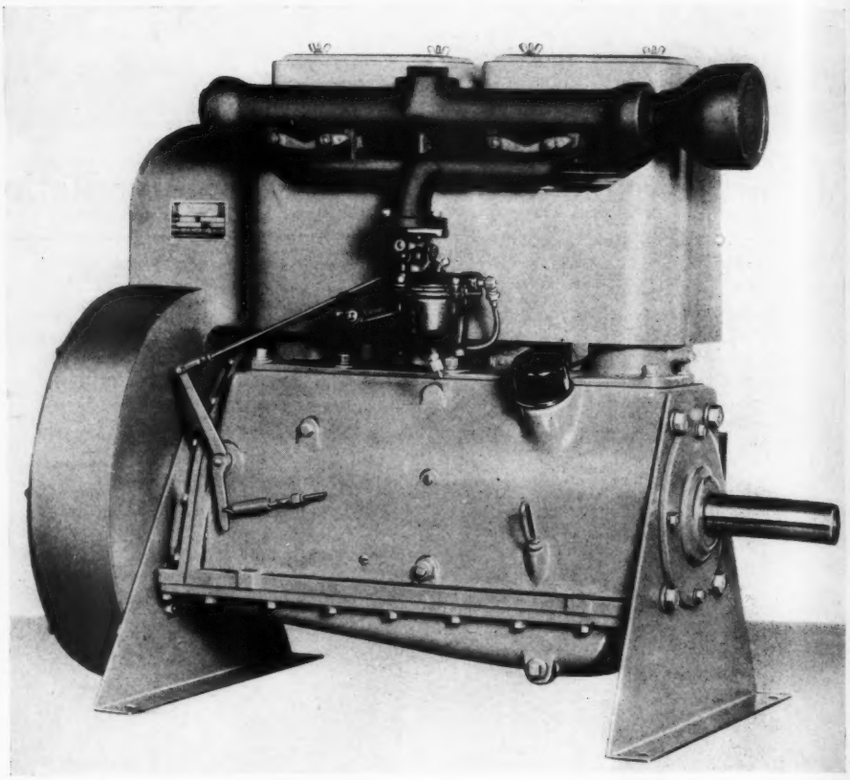
Mercury seal, placed where rotating shaft passes through motor casing, prevents contact of pumped liquid with motor or motor bearings. Mercury is in a rotating cup attached to the motor shaft. A cylindrical sleeve is placed around the motor shaft with one end attached to the motor casing and the other end submerged in mercury, effectively sealing off the liquid pumped. Motor oil can be replenished without disturbing installation.

Modern Designs—Engine Has Combination Fan-Flywheel

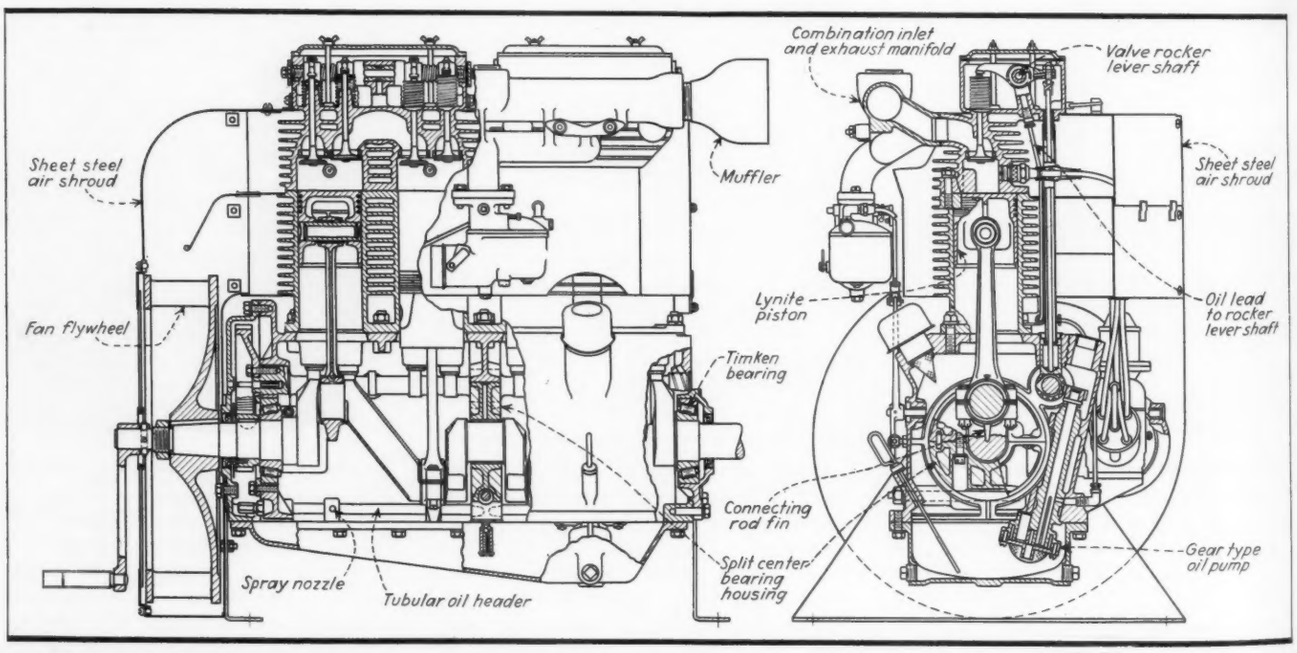
AIR COOLED heavy-duty industrial engine, recently designed by Wisconsin Motors Corporation, is of four cylinder, valve-in-head type with a displacement of 132.7 cu. in. Engine is also available in slightly larger bore with 153.9 cu. in. displacement.

Cooling is accomplished by blast of air from the combination fan and flywheel, directed and proportioned to various parts of cylinder and heads by sheet metal shrouds. Fan-flywheel circulates 105 cu. ft. of air per min. per 100 r.p.m. of the crankshaft. Cooling surface of 18.8 sq. in. per cu. in. of displacement is provided. Since hp. of engine does not increase directly with speed, amount of air circulated per hp. increases slightly with speed. At 800 r.p.m. air circulation is 76 cu.ft. per hp. per min.; at 2200 r.p.m. 82.5 cu.ft. of air per hp. per min. is circulated.

Three bearing crankshaft replaces former two bearing shaft, permitting smaller diameter shaft and reducing weight and deflection. Timken end bearings are used to take radial and thrust loads; center bearing is a precision type babbitt lined, steel-backed bearing carried in a split aluminum housing. Bearing housing is bolted together before assembly into crankcase.

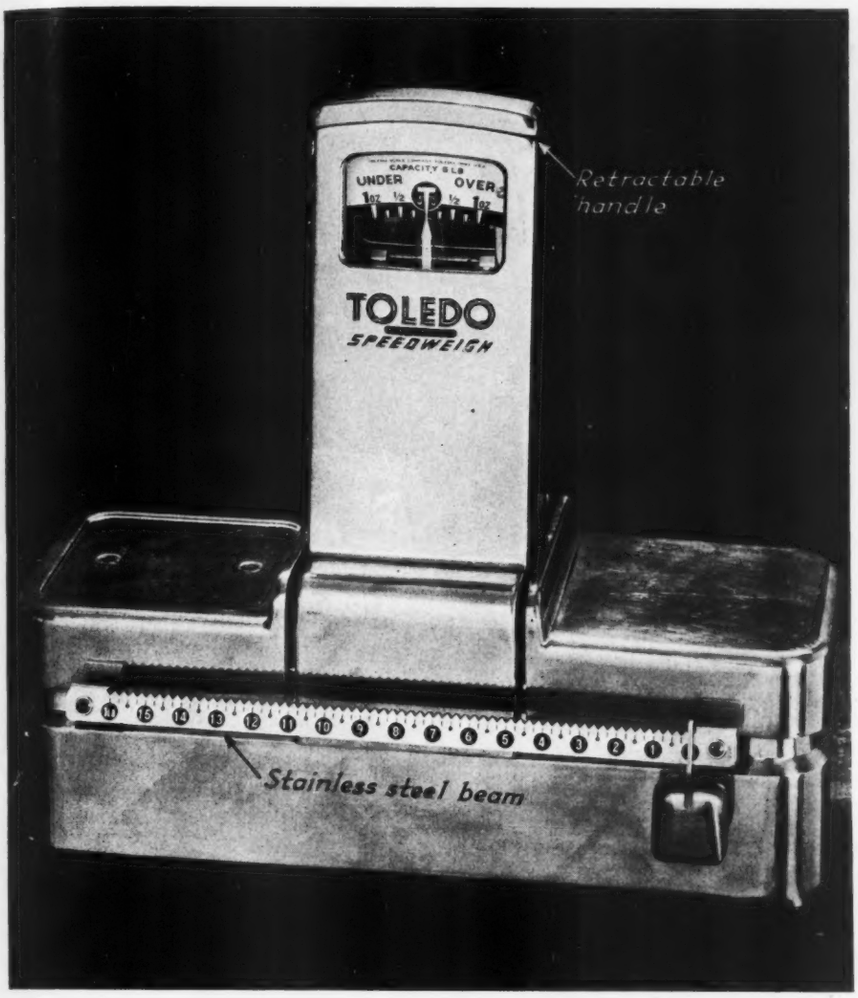


Lubrication is by combination pressure-splash system. Oil is circulated under pressure of 7 to 8 lb. per sq. in. by a gear-type pump to the center main and camshaft bearings and valve rocker lever shaft. Connecting rod caps have fins against which oil streams are directed from main header, so that oil supply to the rods and the resultant spray, which lubricates cylinders and cams, remains constant regardless of the angle at which engine may operate.



Cylinders with cooling fins integral are cast in one block of special nickel alloy cylinder iron. Cylinder heads with cooling fins are cast in pairs of same material. Pistons are cast of Lynite, and carry three compression rings and one oil ring each. Crankcase, oil pan, gear cover and flywheel can be furnished in aluminum, saving 100 lb. Where engine weight is not a prime consideration, these parts are available in cast iron.

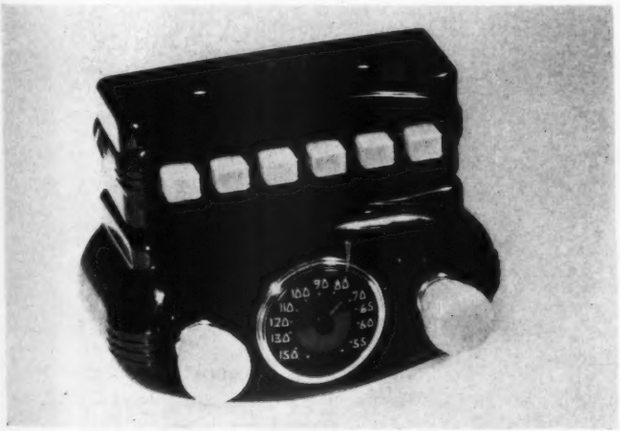
Modern Designs—Aluminum Die Castings Reduce Scale Weight



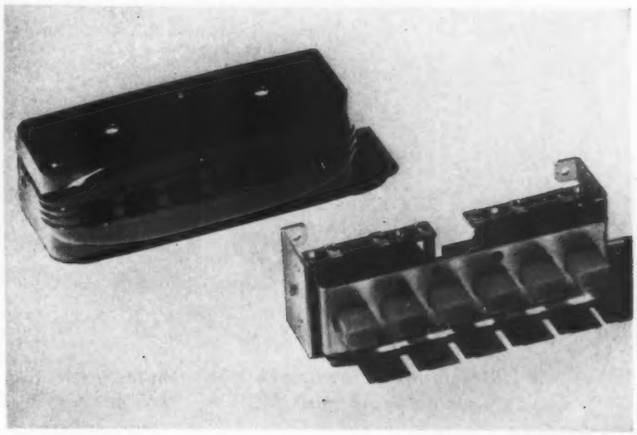
New Toledo "over-and-under" scale, styled by Harold Van Doren and Associates, has aluminum die castings for the base, platters and indicator housing. Scale is assembled with Phillips recessed-head screws. Die-cast aluminum spider and platters, light in weight, decrease inertia in the moving parts and thus increase scale sensitivity. Beam is of stainless steel, with etched figures.

Mechanical features include a self-adjusting dashpot with ball-and-socket connection to lever, indicator mechanism mounted on double ball bearings, and shock-absorbing twin spirals which transmit lever movement to indicator. Pivots and bearings are SAE 1095 heat-treated tool steel. An inbuilt, retractable handle makes carrying easy. Scale is sensitive to 1/64 oz. and total capacity is five pounds.

Automatic Tuning for Automobile Radios



Automobile radio automatic tuning control, designed by Stewart Manufacturing Company, has a two-piece housing injection-molded of Tenite by Elmer E. Mills Corporation. Housing for station-selector switches bolts directly below automobile instrument panel. The larger housing, in which is mounted the hand tuning unit and control knobs, is fastened to bottom of switch housing.



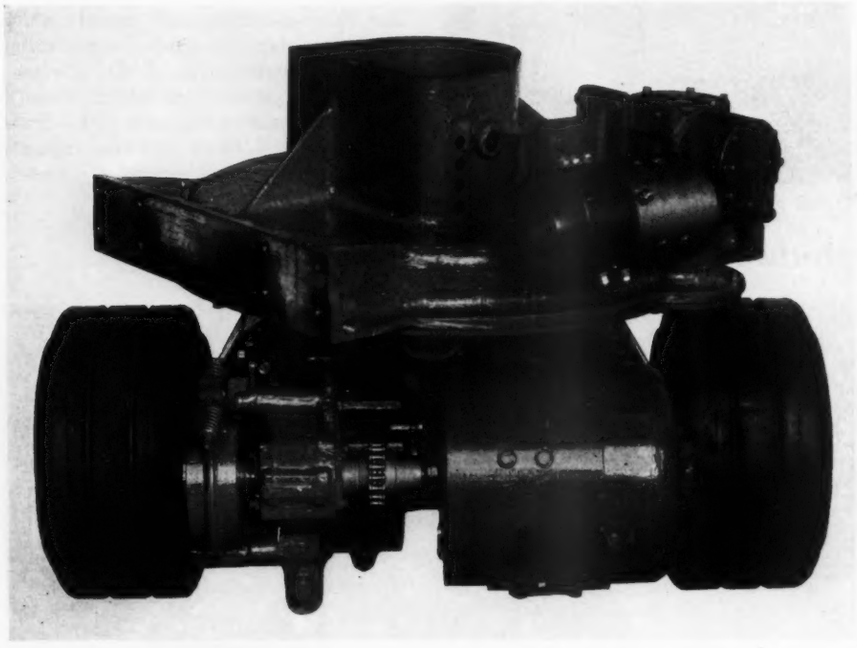
Principle features of this control are light weight and strength. Small housing weighs 1½ oz. and larger housing weighs 2 oz. Walls are 1/16 in. thick and are molded with reinforcing ribs. Single-cavity molds were used for the housings. Multiple-cavity molds were required for the control knobs and pushbuttons which have a recessed slot in face for insertion of station-marking tabs.

Modern Designs—Steers Without Swiveling Wheels

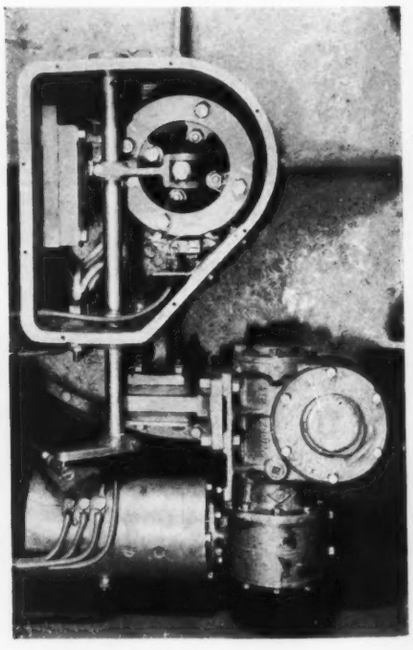
THIS Automatic Transportation Tractor is steered by rotating the frame with its attached trailing wheels relative to a carriage on which the drive wheels and driving mechanism are mounted. None of the wheels steers, since steering is effected by the relative rotation between the main body and the drive carriage. Thus a turning radius of 125 in. is possible with a 90 in. wheelbase.

One-piece heavy-section high-carbon rolled-steel plates, riveted and welded, are used for the frame and side body. Ram carriage is an alloy-steel casting mounted with two pairs of steel-plate cantilevers fitted with wide-faced large-diameter steel rollers which run in roller bearings with perma-sealed lubrication. Uprights, faced with machined plates on which the ram carriage travels, are of heavy H-section to maintain rigidity and alignment. Limit control switches are installed at low and high positions of load, with provision for intermediate stopping or starting at will of operator. Lifting height for ram or forks can be set to suit requirements.

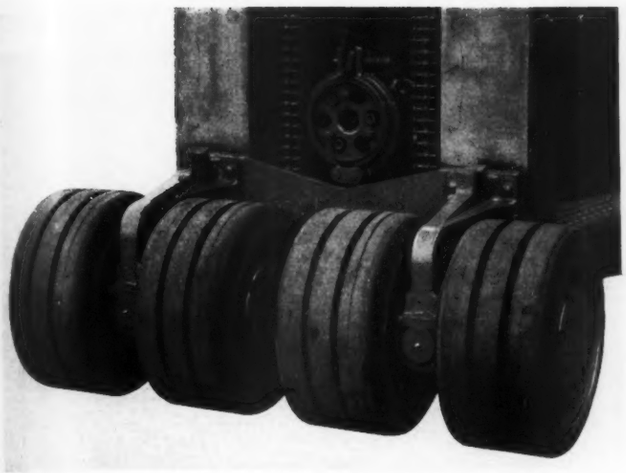
Hoisting and lowering of carriage and loads is accomplished by means of two special double-strand, two-part alloy-steel roller chains, a heavy duty motor, and a combination worm and spur gear transmission.



Drive unit is mounted to steering turntable by a pivoted connection which equalizes traction to compensate for uneven runways and relieves the frame from torsional strain. Forward and reverse speeds are controlled by remote contactor which is arranged for fully automatic acceleration. Universal joints and steering knuckles are eliminated. Large diameter chrome-nickel steel full-floating drive axles are used; these are fitted with splined ends and are heat-treated for strength. Wheels are fitted to axle housings with large adjustable roller bearings. The motorized turntable mechanism combined with the drive unit is a self-contained entirely enclosed gear unit. A separate motor, controlled from operator's station, by remote power steer, supplies power to turntable mechanism.



Insulated central roto-ring with constant tension stator fingers and full limit control for either direction feeds power to drive motor, which drives through a double-reduction spur-geared transmission employing wide-faced heat-treated chrome-nickel steel gears and pinions mounted on shafts with self-aligning ball bearings. Tire drag, pinching and crowding are eliminated.

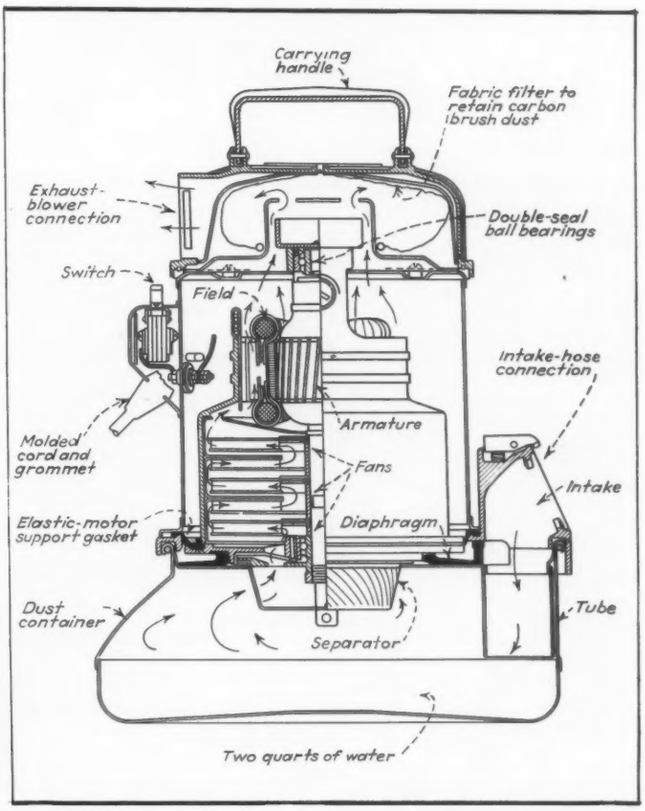


Load wheels are mounted four abreast for more compact chassis construction. This eliminates need for articulated frame or tandem-mounted axles. Wheels are large diameter.

All wheels, tires, wheel bearings are fully interchangeable. Pivoted axles compensate for uneven runways. Straight line of rubber is provided across entire front of tractor.

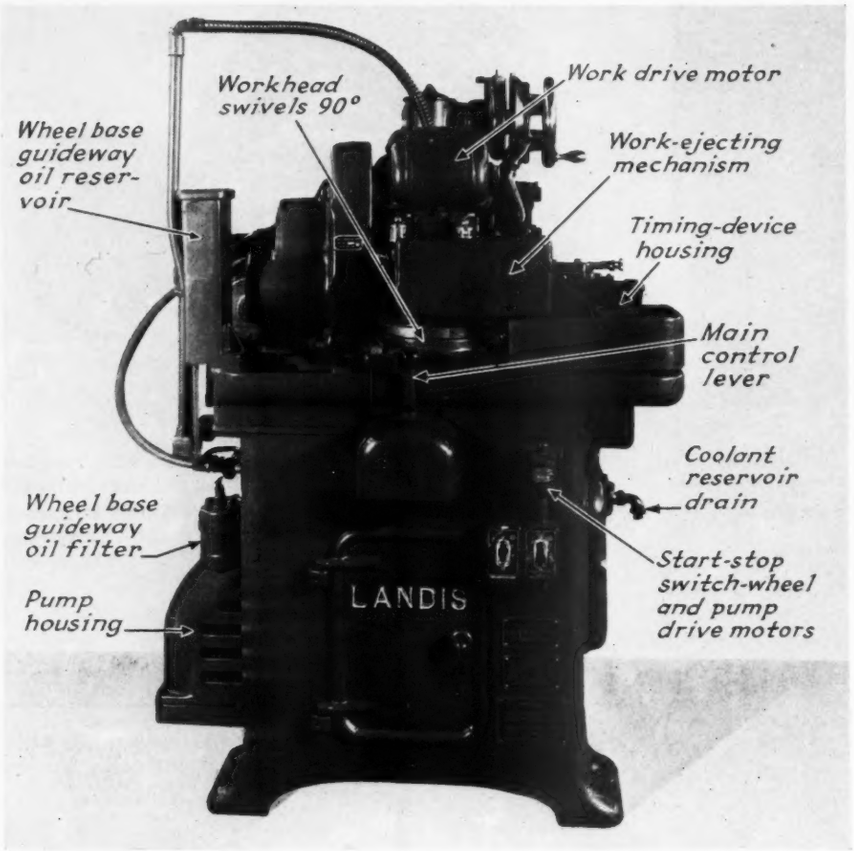
Bagless Vacuum Cleaner Washes Air

With no brush or dust bag, the Rexair cleaner operates entirely on the suction principle. Air and dirt, drawn in through the nozzle, passes through water which washes out the dirt. A centrifugal separator mounted on the motor shaft removes remaining dirt and water globules before air passes through suction fan and motor assembly. Air is discharged through a combination silencer and filter. Motor is cooled by the air stream. Machine displaces 40 cu.ft. of air per min. Dirt is removed by disassembly of water base.

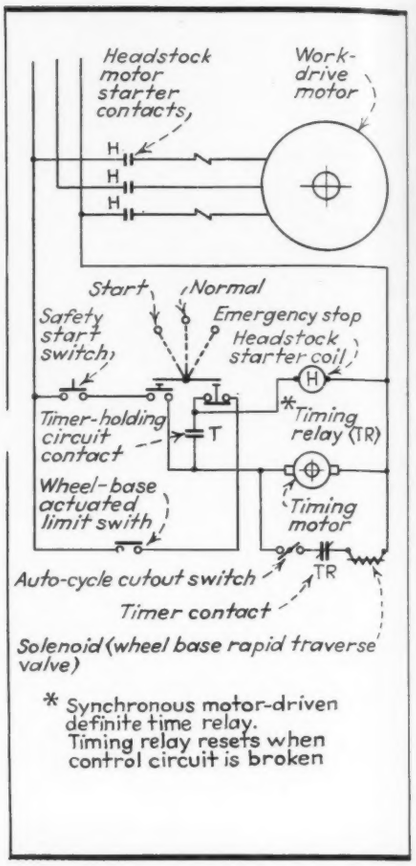


Suction lift of 48-52 in. of water is created by a three-stage fan powered by a Black and Decker motor operating at 13,000 r.p.m. Motor is mounted on double-sealed New Departure ball bearings. Housing is of silicon-aluminum. Advantages of this type cleaner include quiet operation, absence of dust, convenience of dirt disposal, easy portability and good cleaning efficiency which is assured by exceptionally high vacuum employed and by elimination of usual bag which creates back pressure because of dirt-clogged pores.

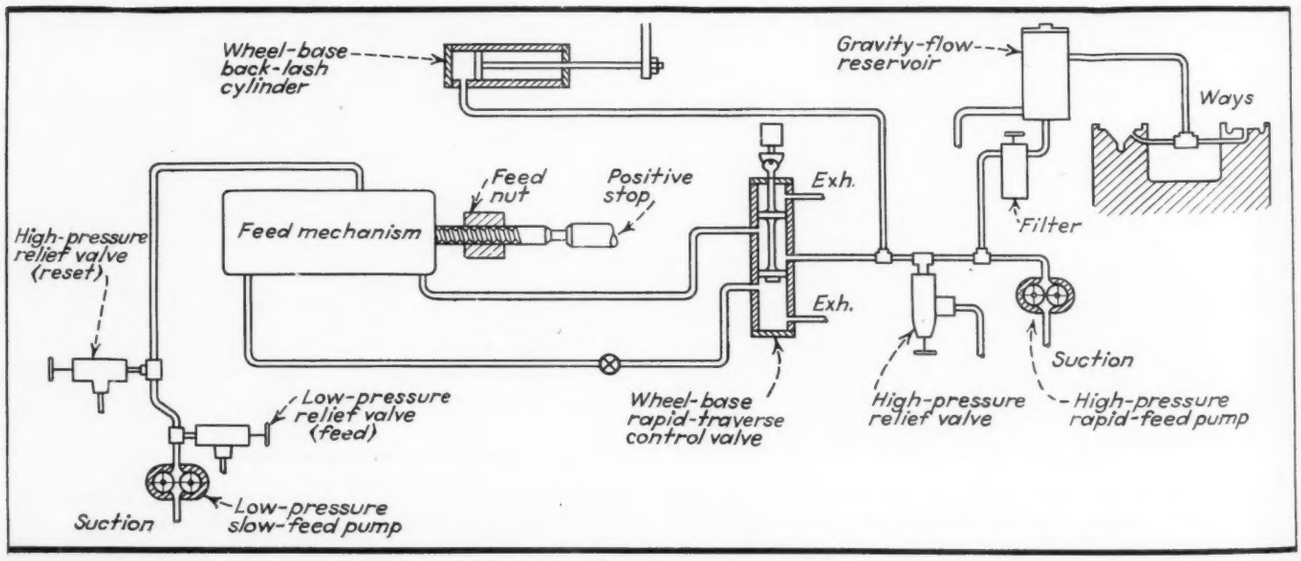
Modern Designs—New Landis Grinder



Hydraulic chucking grinder developed by Landis Tool Company has a work head which can be swivelled 90 deg. and has a solenoid-operated work-ejecting mechanism. Wheel spindle is driven by multiple V-belts from a constant-speed motor mounted at the rear of the head. Speed variation is by means of an adjustable-pitch motor pulley. A second drive off the motor pulley operates the wheel spindle lubricating pump on the machine.



Electric control includes a timing device which regulates the length of the grinding cycle. Wheel and pump motors are started by conventional magnetic equipment. Electric controls are built into the machine.



Elementary hydraulic circuit shows how hydraulic power is used to feed the grinding wheel, true the wheel, and supply guideway lubrication. A herringbone-gear oil pump supplies hydraulic power and is supplemented by a small single stage pump which supplies pressure for the hydraulic infeed mechanism during grinding feed. A reservoir at the left hand of the bed, filled by filtered oil from the hydraulic system furnishes gravity oil feed to the ways. Surplus oil pumped to this reservoir flows back to the main oil reservoir in the machine bed.

Modern Designs

Combination gas-electric range, assembled entirely with Speed-Nuts, and manufactured by Tinnerman Stove & Range Company, has "pop-out" valve controls, four-in-line top, and a single electric lead-in which carries power for electric light, electric clock, and the electric heating element. Valve handles are concealed in upper left hand compartment. Four-in-line burner layout eliminates need for reaching over lighted burners and avoids utensil crowding.

Styling along simple lines is illustrated by this new ironer. Horizontal beading breaks up the flat surface, adds to rigidity and lessens difficulties encountered in finishing large areas. Porcelain enamel top is hung on a compound pivotal hinge; when opened, it swings into position to serve as a shelf for finished ironing. Styled by Lawrence Blazey of Designers for Industry for the Blackstone Manufacturing Company.

Adjustable tension clutch automatically stops driving at a pre-determined point set by a tension-adjusting nut in the Stanley Electric Screw Driver. Powered by a universal motor, this compact light weight tool has an aluminum alloy housing, heat-treated nickel steel gears, and the motor shaft supported on steel-type ball bearings. A double pole trigger switch, fully inclosed, is mounted in the pistol type handle with a lock to hold in "on" position when desired. Phillips bits are available for this tool.

Polaroid lamp recently announced by Polaroid Lighting, Incorporated, provides glareless desk illumination. Light supplied by an ordinary bulb passes through a sheet of transparent Polaroid. The sheet of Polaroid filters out the horizontal light waves which cause glare. Elimination of glare permits focusing of light on the working plane and even distribution over the reading surface. Intensity of light can be increased without a proportionate increase in reflected glare. The light source can thus be placed directly in front of the reader.

RANDOM JOTTINGS ABOUT NEW DEVELOPMENTS

A new magazine-loading movie camera, Filmo 141, manufactured by Bell & Howell Company, Chicago, incorporates new features not heretofore associated with an amateur camera. The camera has a "projected area" view finder similar to those used in Hollywood, four speeds, a single frame exposure device for making of animated cartoons and uses Eastman 50 ft. film magazines.

* * *

Stainless steel cooking dishes, recently put on the market, are designed to be used as serving dishes at the table as well as for cooking purposes, heat-proof plastic trays being provided with each dish.

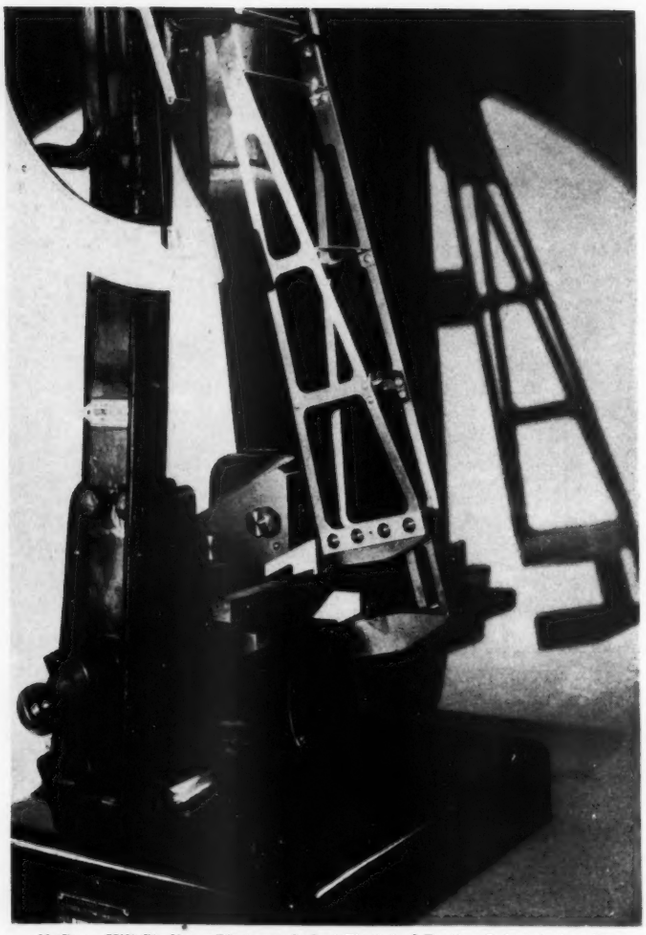
New Shaverlite, designed by Merchandisers, Incorporated, New York, attaches to almost any standard type of electric shaver. Plugged in between shaver and connecting cord, it supplies auxiliary light for shaving.

* * *

New Cunard White Star liner "Mauretania," recently launched, has two cast propellers weighing 25 tons each. Rudder and stock weigh approximately 90 tons, shaft brackets 45 tons and stern frame 40 tons.

* * *

The Mascot Quick-Opening Sheave has a split hook which facilitates threading ropes and cables through the sheave.



McGraw-Hill Studios—Photographed at Electrical Testing Laboratories, Inc.

NOTCH TOUGHNESS

Its Significance and Evaluation

A brief review of some of the divergent opinions on this much debated subject and its relation to design problems

FRACTURING of machine elements or structures in service is almost invariably the result of a minute crack that has grown under repeated stress applications. If either the initial minute crack or its subsequent growth can be prevented, failure cannot occur. Trite as this may sound, this type of failure is now receiving perhaps more attention than any other design problem. Engineering and scientific societies both in this country and abroad are devoting many sessions to discussions of the relations between mechanical properties of materials and this type of service failure. And to date there is no complete agreement on the subject, the investigations thus far not giving conclusive results.

With reference to the initial development of a minute crack, perhaps the most common cause is stress concentration at sharp corners, at abrupt changes in cross-section or at holes such as for bolts, rivets, oil passages, or other purposes. Careful and intelligent design will avoid such stress raising conditions. That is why metallurgists are well justified in denouncing the designers who blame the metal for failures resulting from such points of stress concentration.

But "stress raisers" are also caused by tool marks, cracks developed in pickling or heat-treatment, foreign inclusions in the metal, or by wear, corrosion or other factors encountered in service. Also, points of stress concentration are inherent in some machine elements. Concentrated stresses at the roots of threads are an example. Hence it is important that the relative ability of metals to resist the spread of minute cracks be known. This does not imply that the designer is justified in not analyzing and calculating for concentrated stresses. In many instances such an analysis, though time consuming and difficult, is the only important one, the simple stress calculation being practically worthless.

As pointed out by L. W. Schuster in a paper presented at a meeting of The Midland Metallurgical Societies (England) and published in the January, 1938 number of *Metallurgia*, "The aim in designing a part should clearly be to ensure that the properties of the material are suitable for resisting the form of failure feared most." . . In machinery subjected to severe service, vibratory stresses, impact loads and simi-

lar conditions, creeping cracks are the most common form of failure. Mr. Schuster then explained why the use of the yield point as a basis of design is definitely wrong, why ductility as usually determined is not a measure of ability to resist cracking, and why neither the ultimate strength nor the fatigue limit as commonly determined is a true measure of the ability of the material to withstand service conditions.

Deformation at Yield Stress

Although the yield point of a material in itself cannot be used in design calculations, the amount of strain at the yield point is highly significant. Thus if a material undergoes plastic deformation without appreciable increase in stress, it can correspondingly distribute the initially concentrated stresses over a wider section area, thus relieving the stress concentration to a considerable degree. Mild steel with its relatively low yield strength but high elongation at the yield will have for a given design a lower degree of stress concentration than a heat-treated alloy steel with its higher yield strength. Qualitatively, a material to be suitable for resisting concentrated stresses and severe service should have a relatively large yielding at the yield stress.

Quantitatively, fatigue tests on notched specimens indicate the capacity of a material to withstand repeated concentrated stresses. But such tests, which have only recently come into general use, require a long time to make and the amount of available data on the results of notched-specimen fatigue testing are relatively scarce.

For the purpose of quickly measuring the relative ability of a metal to prevent the spread of a minute crack, metallurgists resorted to notched bar tests, namely, Charpy, Izod and notched tension impact tests. Not all engineers are in agreement on the validity of these tests or the proper interpretation of the test results. So far no one has been able to establish any semblance of satisfactory correlation between the single-blow notch impact test, such as Charpy and Izod, and the ordinary fatigue or notch fatigue test. Furthermore, plotting the results of tension impact tests and Charpy impact tests does not give two parallel curves. The Charpy impact test on notched specimens is generally used.

Regardless of all the shortcomings of the Charpy impact test on notched specimens for measuring the relative ability of the material to withstand impact loads, it is today the best means available for measuring the cleavage strength of a material. Thus it is a measure of the sensitivity of the material to the spreading of a crack, the notch in the specimen serving to establish a point of stress concentration and thereby creating a condition analogous to that created by an incipient crack or sharp angle. The material is said to be notch sensitive or notch tough according to whether the test gives a low or a high impact value.

Notch sensitivity is primarily a hazard in ferrous metals and some of the precipitation hardened non-ferrous metals. These materials have a tendency to propagate cracks at a more or less rapid rate. Some steels, for example, when notched, behave like a brittle metal though their ductility values may be normal when measured by the conventional tension test.

Grain Size

However, notches may be harmful even in "notch tough" materials. In ductile materials the tendency to break by cleavage is greatly accentuated. Coarsening of the grain size also increases the tendency toward notch sensitivity, particularly in carbon steels. Nickel in steel generally has the tendency to increase the notch toughness at and below normal temperatures. At high temperatures the nickel addition has no effect or may possibly cause a decrease in notch toughness. Cast steel and coarse grained steel forgings have low notch toughness.

Steel that has been quenched from too high a temperature will have low notch toughness. In some steels a change of 100 or 200 deg. F. in heat-treating temperature may lower the Charpy impact value 30 to 50 per cent. Curves are given showing the effect of various tempering temperatures on the Izod impact values of a chromium steel.

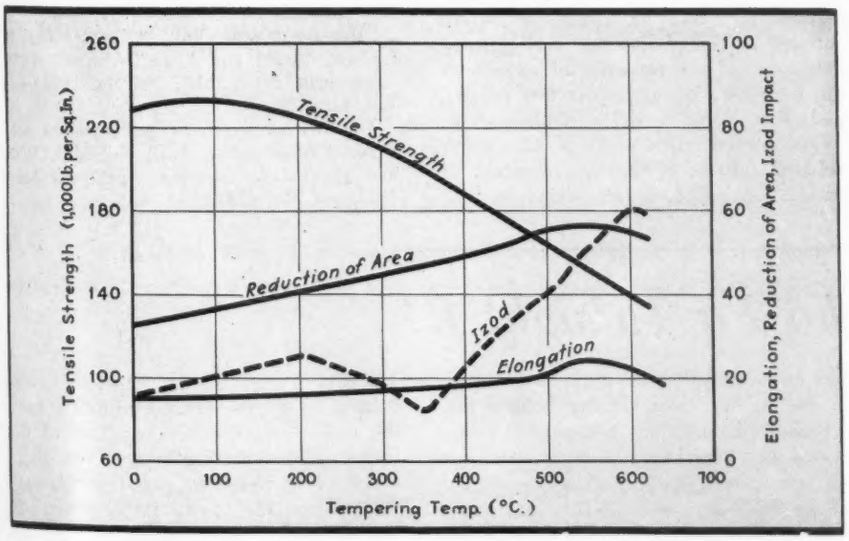
In some steels a few degrees difference from normal temperatures will change toughness characteristics appreciably. For example, a piece of mild steel which was fairly high in its notched bar impact test at 70 deg. F. had very acute notch sensitivity at 32 deg. F. At lower temperatures the loss of notch toughness will usually be more pronounced.

There is apparently no correlation between the tensile and ductility values of a steel, as measured by the conventional test methods, and the notch sensitivity. Two steels having the same tensile strength and ductility may have widely different notch toughness or notch sensitivity. The chief metallurgist of a prominent tractor company reported that gears of SAE 5150 failed in service, while the same gears of SAE 2345 did not, the materials having practically the same tensile and ductility values but distinctly different Charpy impact values. See Ref. 3, at end of article.

It should be emphasized that the Charpy, Izod or any other notched-specimen impact test is not a measure of the ability of the material to withstand impact loads. The presence of the notch in the specimen creates con-

TABLE I — EFFECT OF SURFACE CONDITIONS

Furnace Atmosphere	*Material*	*Depth of Surface (in.)*	*Hardness Rockwell "C"*	*Charpy Impact (ft. lb.)*
Oxidizing	S. A. E. 2345	.....	52	14
Carburizing	S. A. E. 2345	0.0015	52	2
Decarburizing	S. A. E. 2345	0.0015	52	19



Curves showing the effect of tempering temperatures on the Izod impact value of chromium steel

TABLE II — COMPARISON OF PHYSICAL PROPERTIES OF SOME COMMON METALS

Metal	Treatment	Charpy Impact ft. lb.	Strengths (lb. per sq. in.) Ultimate	Proportional Limit	Endurance Limit	Corrosion Fatigue Limit Fresh Water	Corrosion Fatigue Limit Brackish Sea Water
Monel	Annealed	....	81,900	25,000	35,000	.....	.....
	Partially Annealed.	63	83,000	40,000	.....	21,000–24,000	27,000–29,000
	Hard	51.4	127,200	82,000	50,000		
Aluminum	Annealed	....	12,600	....	6,000	4,000–5,000	2,500–3,500
	Hard	16.1	20,800	10,500	8,000		
Al. Alloy	Annealed	....	33,400	15,100	14,000	7,000–9,000	6,000–8,000
	Hard	10.1	69,100	36,800	18,000		
Steel 0.16 C	Water quenched & drawn at 900 F.	54.7	65,700	37,200	85,000	20,000–23,000	6,000–9,000
0.19 C	Water quenched & drawn at 1000 F.	19.4	110,900	65,800	53,000	20,000	.....
Chrom-Van	Oil quenched & drawn at 1000 F.	17.7	150,600	87,500	68,000	18,000–20,000	.....
Chromium-Iron 14.5% (high carbon)	Oil quenched & drawn at 1200 F.	13.4	117,400	41,200	54,000	36,000–38,000	25,000–30,000

ditions of a special nature and hence the test results should be interpreted only from that angle. Thus, the Charpy impact test does give some indication of the ease with which a crack will spread under repeat stress. And for a given material it indicates the effects of temperature, heat-treatments and similar factors on the rate of crack propagation. Also data on failed parts show that a low Charpy impact value commonly accompanies a failure.

When a member develops even a minute crack, it has failed. The value of notch toughness then lies in the ability of the material to resist the rapid spread of the crack, and this is usually a distinct advantage. Also under any condition, the use of a high impact value material gives an added "safety factor" both against the inception of the crack and its subsequent rapid spread.

In the final analysis the resistance of a fabricated structure or machine element to impact or shock is primarily a question of design. The distribution of the metal and the presence or absence of stress raisers are the two main factors to consider. Resorting to the use of high impact value materials should be looked upon as a means for securing added safety against stress raising conditions that are beyond the control of the designer.

The accompanying tables and sketch show some of the factors to be considered in designing parts for severe service. The following bibliography lists some of the reports and papers on the interpretation of impact test results, and lists some articles dealing with stress concentration. As to the much debated subject of the interpretation of impact test data, it all seems to boil down to the fact that in the present state of the art, the notched bar impact test is the best thing we have today for determining the notch sensitivity of a material.

Following references are given for further information on the subject of notch toughness:

(1) G. C. Riegel and F. F. Vaughn, "Practical Application of the Notched Bar Impact Test," A.S.T.M. Annual Meeting, June 27—July 1, 1938. (2) S. L. Hoyt, "Notch-Bar Testing," *Metals and Alloys*, January, February, April and May, 1936. (3) G. C. Riegel, "*Transactions*," American Society for Metals, Vol. 22, 1934. (4) P. Ludwik, "Stahl and Eisen," Vol. 43, 1923. "Zeitschrift des V.D.I.", Vol. 16, 1924, and Vol. 71, 1927.

For articles on stress concentration see: *Product Engineering*, April and May, 1938, and *Product Engineering*, April and May, 1933, and May, 1934.

Who'd a Thought It!

LACQUER finished dental stands got blue or brown streaks on them. The streaks took a long time to develop except when the surface was exposed to direct sunlight which accelerated the action. It was noticed that the streaks followed the lines of the hose, suspended in loops, used for water or air. It took a lot of pondering and testing before it was discovered that the anti-oxident used in the rubber compounding caused the trouble. Changing the anti-oxident eliminated the trouble.

* * *

ALUMINUM cast housings weighing 30 lb. were found to cost less than when cast in gray iron and weighing 108 lb. The difference in material cost was more than offset by the savings resulting from the easier and quicker handling of the lighter aluminum castings in the shop, and the lower finishing cost. Some savings were also made in machining costs. In the finished product, there was no advantage in the decreased weight. Cost was the only consideration.

Preparing standard rotor assemblies for moving to the next machine operation on the rotor assembly line

STANDARD MOTORS

Economies Obtained by Their Use

C. M. SAYRE
Westinghouse Electric & Manufacturing Company

Numerous factors that make the specification of standard motors economical and desirable for the operation and maintenance of appliances and products which have wide distribution

FRACTIONAL HORSEPOWER motors are now being utilized in building various kinds of appliances for use in the home, office, or industry at the rate of about 50,000 units per working day. The number of varieties or different kinds of motors involved is affected mainly by three factors, namely:

(1) Power supply characteristics,

(2) Amount of power required,

(3) How power is applied to the driven machines.

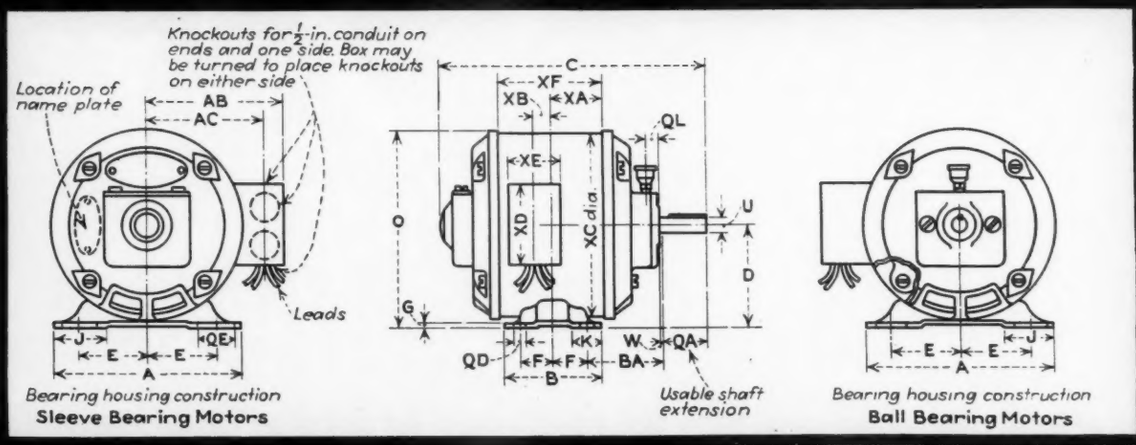
Power supply was a real problem at one time. Farreaching influences, however, have resulted in steadily improving conditions. Today, manufacturers of appliances that are distributed nationally find this particular problem of decreasing importance.

Recognized electrical standards for motors generally include such things as the horsepower, speed, starting and running characteristics. The number of varieties here is under reasonable control and the wisdom of standardization is given a fair amount of recognition. Thus factors (1) and (2) are relatively fixed by conditions.

The third factor, the manner in which the motor is applied, offers the greatest opportunity for constructive improvement in machine and product design practice. Often the first layouts seem to indicate that a motor of special construction will be required. But there is

TABLE I

DIMENSIONS FOR $\frac{1}{8}$ AND $\frac{1}{6}$ HP. SINGLE-PHASE MOTORS



	HP	CYC.	RPM	FRAME	A	B	C SPLIT PHASE	C CAPACITOR START	C REPULSION START	D	E	F	G	J	K	O	U	OD	BA	QA	QD	QE	C-QA LENGTH
Motor Mfg. No. 1	1/8	60	1140	145	6½	4	9 7/8	–	–	3½	2 7/16	1½	5/32	1 21/32	29/32	6 23/32	½	6 7/16	2 11/16	1½	11/32	1 7/32	8 3/8
	1/6	60	1725	145	6½	4	9 7/8	9 7/8	–	3½	2 7/16	1½	5/32	1 21/32	29/32	6 23/32	½	6 7/16	2 11/16	1½	11/32	1 7/32	8 3/8
	"	"	1140	145K	"	"	10¼	–	–	"	"	"	"	"	"	"	5/8	"	"	1 7/8	"	"	"
	"	50	1425	"	"	"	10¼	–	–	"	"	"	"	"	"	"	"	"	"	"	"	"	"
	"	"	"	145	"	"	–	9 7/8	–	"	"	"	"	"	"	"	½	"	"	1½	"	"	"
	"	25	"	B145	"	"	10 3/8	–	–	"	"	"	"	"	"	"	"	"	"	"	"	"	8 7/8
	"	"	"	D145	"	"	–	10 7/8	–	"	"	"	"	"	"	"	"	"	"	"	"	"	9 3/8
Motor Mfg. No. 2	1/8	60	1200	63J	6½	4	10¼			3½	2 7/16	1½	?	?	?	6 13/16	½	6 9/16	2 13/16	1¾	11/32	1 7/32	8½
	1/6	60	1800	63J	6½	4	10¼	10¼		3½	2 7/16	1½	"	"	"	6 13/16	½	6 9/16	2 13/16	1¾	11/32	1 7/32	8½
	"	"	1200	65L	"	"	10 5/8			"	"	"	"	"	"	"	5/8	"	"	"	"	"	8 7/8
	"	50	1500	63J	"	"	10¼			"	"	"	"	"	"	"	½	"	"	"	"	"	8½
	"	"	"	"	"	"		10¼		"	"	"	"	"	"	"	"	"	"	"	"	"	"
	"	25	"	65J	"	"	10 5/8			"	"	"	"	"	"	"	"	"	"	"	"	"	8 7/8
	"	"	"	"	"	"		10 5/8		"	"	"	"	"	"	"	"	"	"	"	"	"	"
Motor Mfg. No. 3	1/8	60	1140	45	6½	4	9 7/8			3½	2 7/16	1½	5/32	?	?	6 21/32	½	6 5/16	2 11/16	1½	11/32	1 7/32	8 3/8
	1/6	60	1725	45	6½	4	9 7/8	9 7/8		3½	2 7/16	1½	5/32	"	"	6 21/32	½	6 5/16	2 11/16	1½	11/32	1 7/32	8 3/8
	"	"	1140	47	"	"	10 5/8			"	"	"	"	"	"	"	5/8	"	"	1 7/8	"	"	8 3/4
	"	50	1425	45	"	"	9 7/8			"	"	"	"	"	"	"	½	"	"	1½	"	"	8 3/8
	"	"	"	45 / 47	"	"	9 7/8	10 5/8		"	"	"	"	"	"	"	½ / 5/8	"	"	1½ / 1 7/8	"	"	8 3/4 / 8 3/4 *
	"	25	"	49	"	"	11 3/8			"	"	"	"	"	"	"	5/8	"	"	1 7/8	"	"	9½
	"	"	"	"	"	"		11 3/8		"	"	"	"	"	"	"	"	"	"	"	"	"	"
Motor Mfg. No. 4	1/8	60	1140	56V	6½	4	10 7/16			3½	2 7/16	1½	5/32	1 13/16	1	6 5/8	½	6¼	2 11/16	1 13/16	3/8	1¼	8 5/8
	1/6	60	1725	57V	6½	4	10 3/16			3½	2 7/16	1½	5/32	1 13/16	1	6 5/8	½	6¼	2 11/16	1 13/16	3/8	1¼	8 3/8
	"	"	1140	56V	"	"	10 7/16			"	"	"	"	"	"	"	"	"	"	"	"	"	8 5/8
	"	50	1440	57V	"	"	10 3/16			"	"	"	"	"	"	"	"	"	"	"	"	"	8 3/8
	"	"	"	58W																			
	"	25	1425	56X	"	"	11 3/16			"	"	"	"	"	"	"	"	"	"	"	"	"	9 3/8
	"	"	"	NONE LISTED																			

* 110 volts only - dual frequency

usually ample latitude in design possibilities in applying the motor and a rational analysis will often show the possibility of using a standard motor construction. This leads to fundamental economies that can be shared by the user, the appliance manufacturer, and the motor manufacturer. The designer who provides for the application of standard motors to his product has many advantages over his competitors who require special motors.

In order that the best motor for the requirements can be selected without necessitating a great deal of redesign, the selection of the motor should be among the first factors to be considered in designing or redesigning apparatus. Too often a delay in making this decision finds the engineer forced to adapt a special motor to his partly finished design, whereas earlier consideration would have allowed the use of a standard motor.

Standard Dimension Sheets

Manufacturers of motor-driven products should provide their designers with standard dimension sheets such as shown in Table I with instructions that when considering a deviation from published standard dimensions, an official decision is necessary. The cost of the final product may be seriously affected by any deviation from standard dimensions. Care must be exercised that the dimension sheets used are recognized standards and not those of any one motor manufacturer. In Table I are tabulated the dimensions of 1/8 and 1/6 hp. single phase motors, as produced by four different manufacturers, having the same essential dimensions.

Among the numerous economies that can be secured by the use of standard motors are: low first cost, low investment, low development cost, and low maintenance cost. The following analysis is offered to justify these four potent statements.

Lower costs in general prevail over the entire range of standard motors for the following reasons. Most manufacturers of motors have a standard line and over the industry a complete line of standard motors is produced. In producing a line of standard motors, much thought has been given to the ultimate cost of the product. To produce at the lowest possible cost mass production methods have been utilized, with provision for slight changes which are made necessary by the various ratings. The type of equipment and tooling required represents a very large investment and can only be justified by volume production.

There are few purchasers of motors whose buying power is such that a manufacturer of motors is justified in investing in similar mass production equipment and tools for their specific needs for motors of special design. It is generally safe to say that special motors are produced on general purpose machines and with temporary tooling. A few manufacturers of motors have gone ahead on the basis of low cost specials, but in the writer's opinion have been forced to absorb losses, because of changes in design, loss of business to competitors, or the decision of the purchaser to produce his own motors. When the latter occurs, it is usually after the design has become stable, and the volume has reached the point where mass production methods are justified.

This condition where the motor manufacturer absorbs losses on specials must eventually be recognized and corrected. There are two methods of correction, namely, increase the price of the specials to the point of profitable operation or discontinue the manufacture of special motors altogether.

The cost of manufacturing usually is the controlling factor in the pricing of a product, therefore, lower prices are inherent with standard motors.

The use of standard motors enables the product manufacturer to operate with the minimum investment in motor stocks. The leading manufacturers of standard motors usually provide ample inventories of finished motors and parts which are available at all times. A few of the larger producers have warehouse stocks at many locations throughout the country. The product manufacturer also has the advantage of multiple sources of supply and therefore is in no danger of shortage at times of peak production or under other circumstances that might apply when there is but one source of supply. Many product makers recognize this as a definite advantage when surveying inventories especially in view of the sudden changes in business conditions that have been experienced in the past years.

Eliminating Development Costs

The cost of development of a motor runs into many thousands of dollars. Such cost of development can rarely be justified for a special application, since it is usually less expensive to adapt the machine to use a standard motor.

Standard motor development costs are amortized over a large volume of sales to many users over a long period of time. Special motor development costs have to be paid over a short period of time. Few applications of motors warrant the cost of development of a complete motor. Most special motors are compromises of standard designs and often provide very little that is not obtainable in a standard motor. Even then the cost of development runs into many hundreds of dollars which can all be saved by designing products to use one of the many standard motors that are available.

Lowest maintenance cost is realized when standard motors are used. Repair and service parts are available at all times, stocks being maintained at many locations over the country by the larger manufacturers. These parts are usually coming through the regular production lines and are produced at low costs.

The reverse of this is true in the case of special motors. Servicing time is increased because parts for special motors are rarely available from stock. Also, servicing costs are higher whether the parts are produced by special runs or in the regular production channels for stock. In the latter case the higher prices are necessary to offset the possible inventory depreciation loss on special parts. Many manufacturers already recognize these facts.

Exchange Servicing

There has also been a major improvement in the field of service on standard motors. That is the so-called exchange plan used by the larger manufacturers. The use of this plan cuts the out-of-service period of motor driven apparatus to a minimum. It provides immediate replacement of the complete motor unit at a nominal cost, averaging less than total costs of repair in field service shops. These units are readily accessible, with a supply at strategic locations throughout the country.

Any manufacturer of motor-powered products is confronted at all times with possible failures in the field. This can be a source of serious sales resistance to his product if not properly handled. The exchange plan of service is a definite sales advantage and should be emphasized. Also the use of such a plan cuts the maintenance costs of the ultimate user to the minimum.

There is still much to be accomplished in the way of standardization on motors. This is particularly true in the field of unit heaters, blowers, oil burners, and similar equipment. Development of standards for these applications is now going on.

Every manufacturer in each industry should endeavor to use standard motors for his applications and thereby reduce the cost of motor-driven products. The motor manufacturer has and will continue to pass along a just portion of savings from standardization to the product manufacturer who in turn can pass same along to the ultimate user. The price trend will always be lower, therefore, the producer of quality products at lowest price will continue to be the leader. In brief, product engineers can secure more and better motors per dollar invested by the use of standard motors than if special motors are used.

ORGANIC FINISHES

J. R. BROSSMAN
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This article describes the physical, weathering, corrosion and other tests, as made in the laboratories of the General Electric Company, on materials used for industrial finishes

ORGANIC industrial finishes used in the General Electric Company, the great majority of which are the Glyptal types, must undergo rigid tests and inspection before they are approved for use and applied to assembled equipment. Investigation must also be made on a constantly increasing number of new materials, and also on special finishes and colors desired by our customers. It therefore necessitates a general testing procedure on incoming standard paints and lacquers and more complete tests and investigation on new materials.

All finishes intended for indoor and outdoor service are tested with the proper undercoat or number of coats as will be used in service. The preparation of the metal surface before coating is very important. There are a few selected ways including pickling, electrolytic descaling, grit blasting, removing grease and oil with carbon-tetrachloride and vapor degreasers. Subsequent coatings prior to painting include priming coats, Granodizing and Bonderizing. Copper is given a thin sulphurized coat, brass a thin oxidized coating, and aluminum a deoxidine treatment. The proper preparation of the metal surfaces is essential for the adhesion of paint or lacquer coatings, as they must become an integral part of the finish scheme if the best protection and long life in service are to be assured.

Applying Finish to Test Panels

Metal test panels are $2\frac{1}{8}$x$5\frac{1}{8}$ in. for weather-o-meter tests, 6x10 in. for general tests, and 8x20 in. for outdoor weathering tests. These panels are properly cleaned by the most desirable method, depending upon requirements, and then properly prepared for coating,

Paint or lacquer to be applied to the test panels is stirred by mechanical means to get all of the pigment into the proper suspension and evenly dispersed. The mixture is thinned to a suitable spraying consistency with the proper solvent. The Zahn viscosimeter, Fig. 1, is used in determining the viscosity. In its operation, a steel bullet-shaped cup with an arrangement for different size orifices at the bottom is suspended by a looped handle in the liquid to be measured. To measure the viscosity the instrument is simply raised from the liquid and the timer started simultaneously. The timer stops automatically when the liquid flowing through the orifice breaks suddenly near the orifice. Accurate measurements can be made in about 30 seconds. Errors due to possible temperature differences between the instrument and liquid are eliminated since the cup remains in the liquid when not in use and is, therefore, always at the proper temperature.

The paint or lacquer is sprayed on the panels with a low-pressure internal mix gun. Observations are made of the approximate drying time, the covering and hiding power and the approximate coverage per gallon. When the panels are dry they are examined for color, gloss, depth, absence or orange peel effect, and similar things. Color and gloss are visually checked against standard panels; and also by means of a General Electric automatic color recording analyzer, the color of the standard and the sample being plotted on coordinate paper and compared for the per cent change in the reflecting power and wave length in millimicrons.

Hiding power of the finish is determined by means of a cryptometer. This consists of a glass plate the upper surface of which is optically flat. A black colored glass is used for light colored materials and a white glass for dark materials. A transverse groove is cut in the upper surface and a scale etched lengthwise of the plate on one side of the groove. Resting on this plate is a second optically flat glass to which is attached a thin strip of steel, so that a wedge-shaped layer of paint may be forced between the plates, the wide part of the wedge being at the end opposite the scale. The wedge ends abruptly at the edge of the groove in the lower plate, which contains a thick layer of the material; the line of demarcation is visible. From the angle of the groove and the scale reading at which the line of demarcation is not visible, it will be possible to calculate the hiding power.

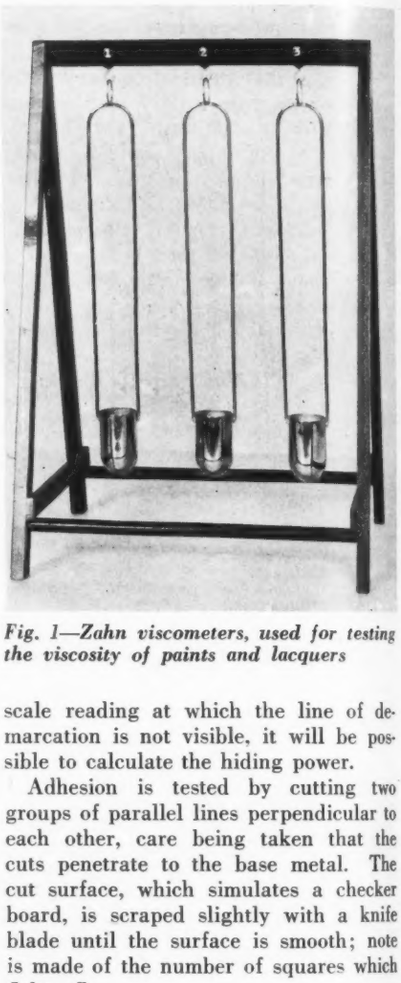

Fig. 1—Zahn viscometers, used for testing the viscosity of paints and lacquers

Adhesion is tested by cutting two groups of parallel lines perpendicular to each other, care being taken that the cuts penetrate to the base metal. The cut surface, which simulates a checker board, is scraped slightly with a knife blade until the surface is smooth; note is made of the number of squares which flake off.

The bending test is another method for testing adhesion. This consists of clamping a standard test panel to a solid base plate and by means of a hinged roller on a bending lever the panel is bent 90 deg. The panels are examined for cracking, peeling and general adhesion of the finish. This test can be made on the original panels or after they have been subjected to a heat and light discoloration test, humidity test and others, depending upon requirements.

Hardness test is made on a panel which is clamped to a solid base plate on which has been fitted a vertical bracket to which is clamped a dial gage, at a fixed distance from the test panel. The bearing surface of the dial pointer is a hemisphere and the pointer is held pressed against the panel for two hours by a predetermined weight. At the end

of this time, the weight is removed and the change in dial reading is taken as the depth of penetration.

Impact hardness is made on test specimen clamped on a solid flat base inclined to an angle of 45 deg. A steel ball is allowed to drop on the film through a vertical tube enough times to rupture, chip or cause the paint film to flow to such an extent that the ball strikes the bare metal. Note is made of the type of failure and the number of times the ball was dropped to cause failure.

Many times finished surfaces are subjected to wear by rubbing, handling and similar causes. A test for this type of service consists of a rubbing machine which has an arm moving back and forth over the painted surface, as shown in Fig. 2. At the end of this arm, resting on the paint film, is a square metal block covered with felt. Pressure is applied to the arm resting on the film. As the rubbing action progresses note is made at various intervals of the condition of the film. A counter attached to the machine registers the number of times the arm has moved back and forth. The face of the block may be covered with a surface other than felt, depending upon the test conditions desired.

When a method of finding the drying time more accurately than can be determined by visual inspection is required, it is determined on a machine such as shown in Fig. 3. The procedure is to spray a metal disk and immediately place it on a slowly revolving turntable. Fine abrasive is slowly fed to the moving plate from a small hole in the bottom of a conical-shaped container, which is supported on a moving screw which carries it directly across the plate. This screw arrangement is for the purpose of depositing the abrasive on the plate in the form of a spiral. When the plate has run for a predetermined length of time, it is removed and the excess abrasive is tapped from the plate. The point where the abrasive ceases to adhere determines the drying time of the film; the time being calculated from the number of revolutions the disk had traveled and its known r.p.m. The plate is geared for three different speeds.

Weathering Tests

Where finishes are required for marine atmospheres, salt spray and salt water immersion tests are made. The salt spray is an atomized brine solution. The panels are suspended in a salt spray box and subjected to the brine mist. The immersion tests are made in a brine solution, with panels only 50 per cent immersed. Inspection is made every day and note made of the condition of the surfaces.

For high humidity tests at room temperatures, the finished panels are suspended in a suitable chamber having a constant temperature and high moisture content. These tests are run mainly to observe if there is any corrosion from the incomplete removal of the cleaning solutions used in cleaning the original metal plate. Corrosive salts may be formed in the presence of moisture and deteriorate the film or cause salts to be deposited on it.

Weather-o-meter tests are a form of accelerated corrosion which are made on standard sized panels, supported in holders in a revolving metal drum. On each revolution the samples are subjected momentarily to a water spray. This water coating is then dried by the heat and rays of an arc lamp directed against the samples. The glass globe on the arc lamp gives off rays equivalent to the sun's rays in June. The spectral range and per cent of total radiation to limit of Fluorite transmission in infra-red are obtained from a table prepared by the Pacini Laboratories in Chicago. The panels are inspected periodically for gloss, bleaching, checking, chalking and corrosion of the metal. At the same time check tests are made by comparison with panels which have been placed on the outdoor weathering rack. This is a standard panel fence placed on the roof of a building where the panels are placed at an angle of 45 deg., facing south.

Films which are subjected to oil, such as the coatings on breakers and transformers which are in contact with the oil in the tanks, are tested for resistance to oil by immersing the paint or lacquer film, preferably on a glass panel, in transil oil. The panel is examined for deterioration of the film and the oil is tested for change in dielectric strength, comparison being made with the dielectric strength originally.

Arcing tests are made on the surface of films applied to glass or unglazed porcelain to determine creepage characteristics across the film. This is done by placing two tungsten pointed electrodes on the film. An interupted arc current is applied in steps until the film breaks down by carbonization. An arc resisting film is necessary on the front of switchboards and similar applications where there is to be no creepage of electricity.

Additional tests include heat, discoloration, corrosive action of gases and others, but these are not made unless occasion demands and the finish is to be used on special applications.

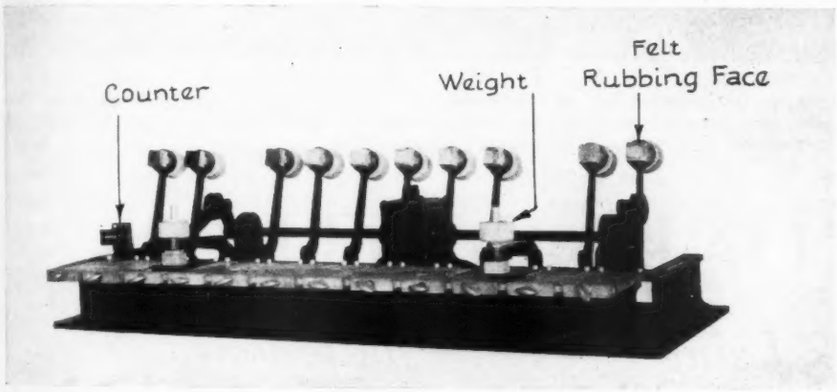

Fig. 2—Machine for determining the rubbing life of a finish film

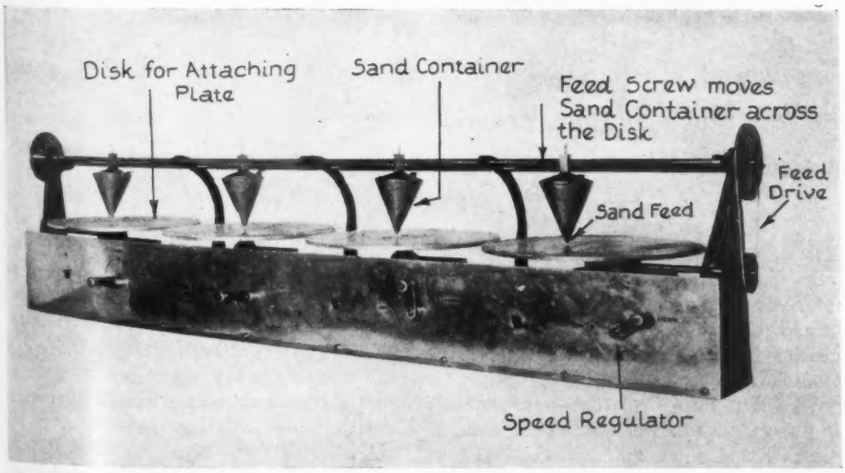

Fig. 3—Machine for determining accurately the drying time of paint or lacquer films

Fig. 1—Complete photo-electric amplifier used for sorting rock salt. Amplifier itself is housed in a glass case to eliminate possible corrosion, while the photocell and its light sources are mounted in an enameled unit. Variations in reflected light because of color differences in the salt cause automatic rejection through a solenoid operated air valve

ELECTRONIC CONTROL

Applications Using Special Equipment

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Specially designed and custom engineered electronic control equipment which can be built into machines to time process operations and to detect automatically defects in product

IN THE ARTICLE "Electronic Control —Typical Applications" which appeared in June *Product Engineering*, some simple "on" and "off" adaptations of photoelectric cells, associated amplifiers and relays were explained. General circuits and procedure of application to obtain frictionless control of automatic machines, of safety devices and of conveyors where an opaque object passed into the actuating beam of light, were also described. In the space available only generalities could be dealt with. yet some of the specific installations required considerable thought and engineering before advantageous results were obtained.

This article will cover in a general way more advanced or custom engineered controls and their applications. Today almost all of the special photoelectric and electronic equipment has been placed in machine tools. Some of this equipment, however, has been engineered into products as, for example, presses, continuous tube mills, and welding machines.

Electron tube applications of the more exacting or custom engineered types are numerous. About 90 per cent of the startling adaptations of "electric eyes" or "electron tubes" reported in daily newspapers refer to the specific, that is, tailormade and engineered uses of tubes. A mere door opener controlled by a beam of light no longer mystifies the reporter. A laboratory experimental set-up which might enable the blind to automatically read books is "headline" news, and probably would be so cleverly written up that

the reader of the newspaper would hardly realize that the apparatus is still in development in an experimental laboratory and is far from being a commercial reality. Many of the tailor-made and custom engineered uses of tubes, however, are now commercially reliable, and are performing their exacting functions daily.

During the past several years a motor car manufacturer has been working on a problem, involving the inspection of small permanent mold castings which he uses at 16 stations in an automotive engine. After machining these pieces are inspected for cracks, flaws, and blow holes in the casting, by merely tumbling the pieces over on a steel surface plate. If without cracks or flaws they ring like a bell producing fairly uniform sound frequencies for a given duration of time, while similar pieces with cracks or flaws will ring with a different frequency and the duration of ring will be shorter, much the same as the non-resonant sound of a cracked bell.

The attempt to inspect these castings automatically required considerable experimental work, careful observations, and a period of time before the finished microphone, amplifier and time-delay tube could be delivered to the user. The microphone was made as directional as possible to prevent room or shop noises from entering this element of the automatic inspection circuit. The amplifier was equipped with filters, which allowed only the desirable frequencies to reach the time delay circuit. If the casting was struck sharply and was passable, the amplifier passed sufficient energy to initiate starting of the time delay. If the duration of the "ring" was sufficiently long, the output circuit of the time delay would close a relay allowing the piece to pass without automatic rejection. The microphone is shown in Fig. 2 with the automatic hammer and the amplifier unit in which is a self-contained gaseous tube time delay.

The complete unit when finished operated satisfactorily in the laboratory, but when placed upon the complete automatic machine the noise of other tappets being rejected at various stations simultaneous with this listening or sound station caused considerable difficulty. It is anticipated that in order to correct this trouble, the sound station will have to be constructed on a separate mechanical machine.

In the process of making atomic hydrogen welded tube in a continuous rolling, forming and welding mill, occasionally the mandrel or swimmer becomes broken and is carried with the material into the forming rolls, and sometimes as far as the welding operation. Carrying this mandrel into the forming rolls generally results in expensive damage to the complete mill. A d.c. coil and d.c. pickup and amplifier were introduced which allowed the current passed from the d.c. coil to the pickup coil when the mandrel passed, to initiate circuits, immediately stopping the mill. In Fig. 3 a simple circuit of the entire arrangement is shown. In Fig. 4 the amplifier with transmission and pickup coil are shown.

Several attempts to determine the porosity of die-castings have been made, with some success. The process of inspection is simple and satisfactory results can be obtained by studying the electrical and mechanical problems involved. Across the section at which porosity inspection is desired a low voltage is applied. If the section of the die-casting is fairly heavy a transformer is needed to produce sufficient voltage. If the die-casting is not porous it will draw more current than one which is porous. As a result there will be a greater voltage drop between the two connecting electrodes of the non-porous casting. These voltage changes are very small. A vacuum tube voltmeter with self-contained rectifier and amplifier can measure these small changes in voltage drop, and may be used to operate rejection or indicating relays. The irregular shapes of the die-castings, however, do not permit the mechanical-electrical contact with the piece under inspection to have less electrical resistance variations than those produced by the porosity of the casting. In the laboratory the complete device performs perfectly, but in routine inspection the variations in electrical contact with the casting are greater than the variations caused by the porosity. The die-casting can be designed so that correct porosity inspection may be obtained, but this requires consultation and co-

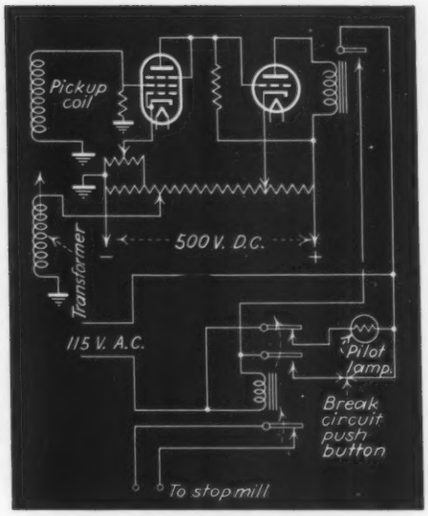


Fig. 3—Hook-up diagram and circuits of elements used to detect broken swimmers in continuous rolling, forming and welding mills. The transmitting coil and the receiving coil are housed within one brass container but for simplification of the circuit diagram they are shown here as two separate coils. The transmitting coil has a certain applied d.c. potential and as the steel mandrel passes from the transmitting coil into the pick-up e.m.f. is generated to make the grid of the first stage of amplification sufficiently positive. As the mandrel passes beyond the pick-up coil, the grid of the first tube is again returned to a negative position, thereby closing the relay in the plate circuit of the final tube. The control relay electrically latches closed, opening the contacts controlling the mill and closing contact for pilot lamp

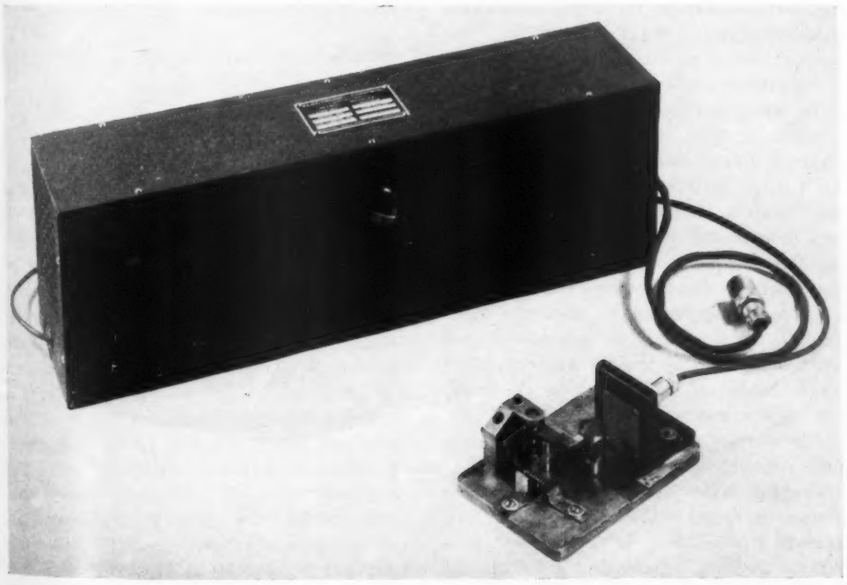


Fig. 2—Equipment for inspecting a small machined casting for cracks, flaws and blow holes. The casting when struck by the automatic hammer gives off a ringing sound that is picked up by the microphone mounted on the testing fixture. An amplifier to which the microphone is connected is housed in the cabinet. The amplifier is equipped with filters which allow only the desirable frequencies to reach a time delay circuit. If the duration of the "ring" is sufficiently long the output circuit of the time delay closes a relay which allows the piece to pass

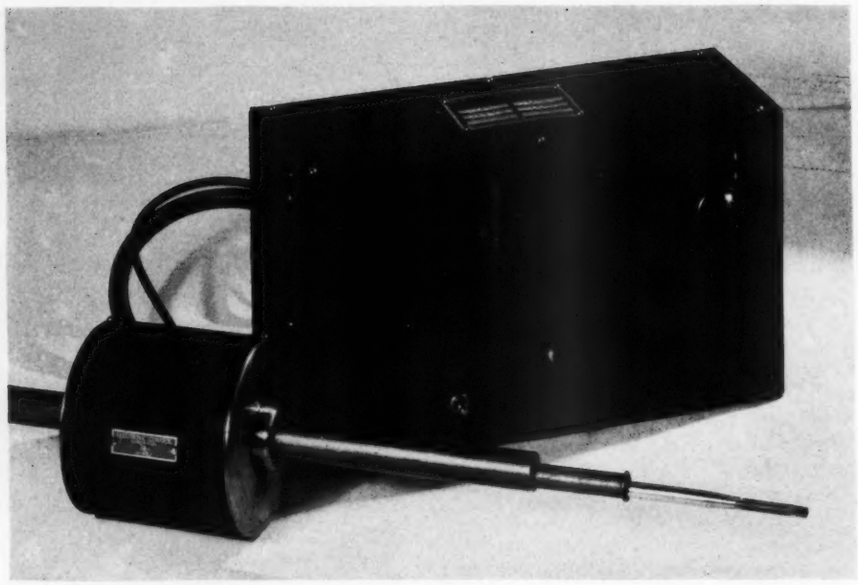


Fig. 4—Complete broken swimmer detector unit. The d.c. coil and magnetic pick-up coil are housed in the tubular structure in the foreground. The mandrel or swimmer is shown in the center with the tube which is being formed directly around the swimmer. As the mandrel passes between the magnetic coil and the pick-up coil sufficient e.m.f. is generated to electrically latch the amplifying circuit thereby stopping the tube mill and lighting the indicating pilot lamp

operation between the die designer and electronic inspection engineers before the unit is placed in production.

An accurate method of delaying operations after one has been initiated makes use of a tube. The method is based on the following considerations: At a given potential and a given resistance value the rate of charge of a good condenser will be accurate; the operation of vacuum tube or gaseous tube time delays are based upon the charging time of a condenser; and with fixed capacity, fixed resistance and varying voltage the time can be adjusted. In Fig. 5 a simple vacuum tube time delay is shown, in which after the initiating contact is closed the condenser in the grid circuit slowly starts to make the grid positive and accordingly the plate current of the vacuum tube increases, then at a critical point the relay becomes energized and closes. The variation in time of closing the plate relay after closing initiating contacts may range from a few hundredths of a second to three minutes in the standard time delay. Adjustments of bias as shown in the circuit are easily made to obtain correct time of delay following initiating operations.

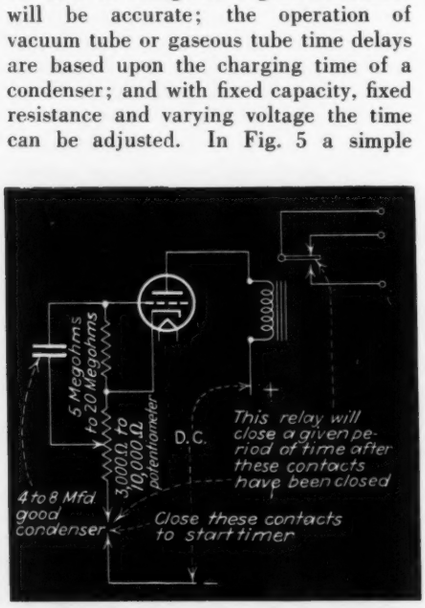

5 Megohms to 20 Megohms
3,000Ω to 10,000Ω potentiometer
D.C.
This relay will close a given period of time after these contacts have been closed
4 to 8 Mfd good condenser
Close these contacts to start timer

Fig. 5—Vacuum tube time delay for delaying operations. When the lower contacts on the negative side of the supply are closed the condenser slowly becomes charged causing the grid of the tube to slowly obtain positive potential and after a predetermined period of time, ranging from a few hundredths of a second to three minutes, the plate circuit will pass sufficient current to close the relay

An interesting application of a vacuum tube time delay is the inspection of diaphragm type fuel pumps which are used on automotive and aircraft engines. To pass inspection, it is necessary for the pump to deliver a given amount of fuel in a stated period of time. Operating the pump at constant speed is comparatively simple but since the pump delivery was to be measured over the short time of 20 sec. plus or minus one per cent, a problem in timing was presented which could not be solved by the average synchronous clock motor timer. Vacuum tube time delay being much more accurate answered the problem.

Vacuum tubes and gaseous tubes are frequently used for accurately timing welding operations. In high-speed production welding where timing within ½ cycle at 60 cycles per second is required to obtain clean flawless welds, large gaseous tubes commonly referred to as Thyratrons are used as switches to turn the primary of the welding transformer on and off. The absence of moving parts is also an advantage in this method of timing.

Ordinary amplifiers with cathode ray tubes are also used to determine reverberation periods in metal objects, to control inspection and to analyze frequencies.

The application of a photo-electric cell to a scleroscope might seem to be a comparatively simple installation. However, a standard light source, which projects a beam of light one or two inches in diameter will not produce sufficient light cut-off at the photo-electric cell to initiate relay control. If a light source is used that will project through the glass tube of the scleroscope a very small beam of light measuring ⅛ in. in width and 0.005 to 0.006 in. in thickness, the scleroscope hammer when passing through it will cause complete eclipse. By using a photo-electric amplifier with sufficient light sensitivity to operate on the small amount of light transmitted through this slit, accurate photo-electric scleroscope operation can be obtained.

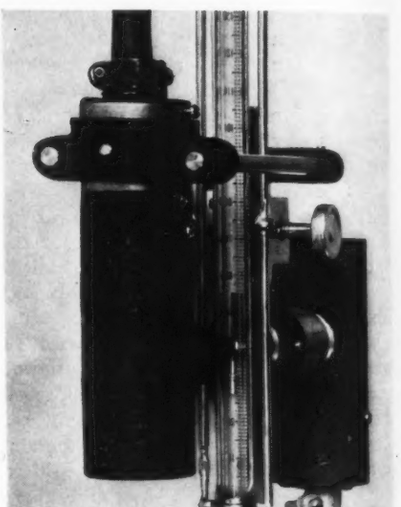


Fig. 6—Scleroscope of the conventional type with light source attached at back and photo-electric cell with housing at the front. The small hammer is shown on the rebound

In some installations a cam on the machine upon which the photo-electric scleroscope has been installed cuts the photo-electric equipment out of the circuit during the falling stroke of the hammer, and then later restores the photo-electric circuit as the hammer reaches the object under inspection. In Fig. 6 is shown a scleroscope of the conventional type with light source and cell housing attached. The scleroscope hammer can be seen traveling into the ribbon of light.

WHAT IS NOT INVENTION–IV

H .A. TOULMIN, JR.
Toulmin & Toulmin

This fourth article in the series discusses the patentability of those inventions or advances in design which are made as the natural and proper outgrowth of the development of a product

BECAUSE I have found that engineers and designers are prone to overlook the fact that inventive genius is the only quality which justifies, under the law, the issue of a patent, I have repeatedly stressed that point. The Supreme Court has said:

"The process of development in manufactures creates a constant demand for new appliances, which the skill of ordinary head-workmen and engineers is generally adequate to design, and which, indeed, are the natural and proper outgrowth of such development. Each step forward prepares the way for the next, and each is usually taken by spontaneous trials and attempts in a hundred different places. To grant to a single party a monopoly of every slight advance made, except where the exercise of invention, somewhat above ordinary mechanical or engineering skill, is distinctly shown, is unjust in principle and injurious in its consequences." This is the rule which governs the following unpatentable types of "invention."

1. Durability. The durability of a product is plainly a matter of engineering. The inventive faculty is not needed to reduce the wear of a machine by equipping it with ball bearings, or with a superior lubricating system. To make a part of hardened steel instead of soft steel, of metal instead of wood, or to eliminate a part that is structurally weak and unnecessary—in fact to improve the wearing capacity of any product is routine development. Here are three court decisions bearing on different phases of this subject.

One court held: " . . . it was no invention to stiffen by artificial means the leather cross-piece which had before been made as rigid as it could be by thickness, doubling and stitching. All that had been done by this inventor was to add to the degree of rigidity which had been used before. The addition of metal or other substance as a stiffener of the known cross-piece, which had already been made rigid in a degree, was not invention. The substantial elements of a well-known structure were thus, in no patentable way, changed. . . . All he did was, by the use of known equivalents for some of the elements of former structures, to make it somewhat better than it was ever made before. This is not patentable."

Again: "The appellant contends that the Anson machine fails to be an anticipation of the Woodbury invention, because, as they say, it has no solid bed. It plainly has, however, a solid bed, adequate for the purpose for which the machine was intended and used—for cutting and planing light material, sash and blinds—and the bed is sufficiently solid for such uses. It may be admitted that it would be too weak for general planing work upon boards or plank. It is comparatively a small machine. It would not cease to be the same machine, in principle, if any one or all of its constituents were enlarged or strengthened, so that it might perform heavier work. . . . The simplest mechanic can make such a modification."

One other case: "Some evidence was given to show that the wagon reach of the plaintiff is a better reach, requiring less repair, and having greater solidity than the wooden reach. But it is not sufficient to bring the case out of the category of more or less excellence of construction. The machine is the same. Axe-helves made of hickory may be more durable and more cheap in the end than those made of beech or pine, but the first application of hickory to the purpose would not, therefore be patentable."

2. Convenience. It is not invention merely to make a device more convenient, easier to use or portable. That is mere change of degree which, as has been seen, is usually not patentable because it is held to involve only ordinary mechanical skill. The court held in one case: " . . . Hoffman may have succeeded in producing a shelf more convenient and more salable than any which preceded it, but he has done it principally, if not wholly, by the exercise of mechanical skill."

3. Portability. Portability is a type of convenience on which many patent applications are based, but usually whether a device is portable or stationary has nothing to do with invention. This has been often held by the courts. For example, the Supreme Court said in one case: "Merely putting rollers under an article so as to make it movable, when without the rollers it would not be movable, does not involve the inventive faculty and is not patentable."

Again a court held: "We do not understand, however, that it constitutes invention so to alter a case made to contain several maps that it shall hold but one, or to make a case of lighter material so that it shall be portable, or to make it ornamental or attractive. To do this may prove greatly beneficial and convenient, but it is not invention."

4. Selection of materials. Part of the routine duties of engineers and designers is to specify the materials which shall be used in a device. To use materials in a way that utilizes only their known characteristics is not invention. The use of materials is patentable only when they are used in such a way as to disclose a previously unknown quality of the material or when a new and unexpected result is achieved by its use. Then only, may there be invention in the use of a new material.

It has been held by the court: "The use of one material instead of another in constructing a new machine is in most cases so obviously a matter of mere mechanical judgment, and not of invention, that it cannot be called an invention, unless some new and useful result, an increase in efficiency, or a decided saving in the operation, is clearly attained."

Thus it has been held not to be invention to substitute metal parts for those of fiber or wood, or liquid glue in place of melted dried glue as a lining for barrels.

By contrast, it has been held patentable to substitute hard rubber for a dental plate in place of the materials previously used. The court said in this case: " . . . (this) produced a manufacture long sought but never before obtained—a set of artificial teeth, light and elastic, easily adapted to the contour of the mouth, flexible, yet firm and strong, consisting of one piece, with no crevices between the teeth and the plate, impervious to the fluids of the mouth, unaffected by the chemical action to which artificial teeth and plates are subjected when in place, clean and healthy—peculiarities which distinguish it from everything that had preceded it. These differences are too many and too great to be ascribed to mere mechanical skill. They may justly be regarded as the

result of inventive effort, and as making the manufacture of which they are attributes a novel thing in kind and consequently patentable as such."

It is apparent that there is a very clear-cut line between what is patentable and what is not in the selection of materials. It should not be difficult for an able designer to tell the difference, in most cases.

5. Use for analogous purposes. Many of the branches of science and engineering are so closely related that in patent law parlance they are spoken of as "analogous arts." Thus the manufacture of paint, dyes, explosives and other chemicals are analogous arts. Generally speaking, to adapt a machine used in one art to an analogous one is not invention—but whether or not that has been done is often a case for the court to decide, for a rule is involved which frequently calls for judicial decision on the basis of the facts brought out by the evidence. This rule is that if the inventor could naturally be expected to be familiar with the analogous art no invention is involved, but if the arts are so different that the inventor could not be expected to be familiar with both, invention may be present.

In a case involving the application of the phonograph principle to talking pictures, the court held: "Even if it be assumed that the Greensfelder patent did not anticipate that of respondent, because the sound record there mentioned was designed directly to operate musical instruments, rather than a loud-speaker, all that was novel in the claimed method was its application in the production of a combined sound and picture record, instead of a combination of two picture records. . . . The application of an old process to a new and closely analogous subject matter, plainly indicated by the prior art as an appropriate subject matter, is not invention. . . . However wide the differences between the procedures and results of sound reproduction from film on the one hand, and picture reproduction on the other, the method of producing photographic sound and picture records and uniting them on the positive film are identical, for both the sound and picture records, from the time of exposure of the negatives until the single film is completed. With knowledge of the well understood advantages of the union of the two records on a single film, it required no more than the expected skill of the art of photography to use an old method of printing photographically the two negatives upon a single positive."

6. Aggregation. In an article which appeared in the July 1937 issue of *Product Engineering* I discussed in some detail the difference, under the patent laws, between combinations and aggregations and explained why combinations that serve a new and useful purpose are patentable and why aggregations are not.

Briefly, a combination is patentable because the result achieved is different from, or greater than, the sum of the results of the various parts which go into it. An aggregation, however, gives no different result than would be secured from its parts used separately. To be patentable the parts must interact to modify the action that would be expected. An aggregation, in short, is merely a collection, a loose association, of parts acting independently.

Innumerable decisions to this effect have been handed down by the courts. Here is one: "In the gearing specified every element is old. The operations of the wringer and the washing machine, although simultaneous, are independent one of the other. The control of the operation of the wringer is by an old and well-known method. From the cooperation of the elements, here brought together, no new result, involving the exercise of the creative faculty which is invention, is achieved. Phillips may have produced a more convenient and economical mechanism than others who preceded him, but superiority does not make an aggregation patentable. The assemblage of the old elements, and their operation in the manner indicated, may save time, and the mechanism may meet with a readier sale than other similar devices, but these things may result from mechanical skill and commercial enterprise, and do not necessarily involve invention. . . . The combination . . . fails to show that exercise of invention producing a novel and useful result from the cooperating action of the elements, which is essential to distinguish patentable combination from an aggregation of old elements so placed by mechanical skill as to do work more rapidly and economically."

That example of an aggregate of a washing machine and a wringer makes clear the points of difference between patentable combinations and unpatentable aggregations.

[Editor's Note: This article concludes the series "What Is Not Invention." The next article on this subject by Mr. H. A. Toulmin, Jr., will begin a new series entitled "What Is Invention" which will enumerate the positive rather than the negative aspects of new and useful ideas which may be patentable and that are of interest to designers and inventors.]

•

Current Quotations

"We know so little about nature's basic underlying principles that it is incredible that anyone should think that our knowledge of natural laws is anything but exceedingly small when compared with the vast amount that is listed in the unknown column."—M. W. SMITH, *Manager of Engineering, Westinghouse Electric & Manufacturing Company, in an address before the American Association for the Advancement of Science.*

"Research is one of the keystones upon which further world progress depends. It enters into the field of agriculture, communication, transportation, public health, energy, and the production of industrial products. There is a definite interlocking of all of these groups. Each one is dependent for its prosperity and advancement upon the others. All must look to research as one of their foundation stones.

"The 'handwriting on the wall' is clear. The findings of research are needed for our continued progress and prosperity. No field is an exception. Sponsorship of research, therefore, must and will be continued at an ever accelerating rate. Such sponsorship must be in the fields of both fundamental and applied research. Every encouragement, therefore, should be given to those individuals and agencies engaged in research so that, through their achievements, research may contribute its share in restoring prosperity, improving standards of living, and adding to our store of cultural values."—DR. A. E. WHITE, *retiring president of the American Society for Testing Materials in an address before that society.*

"But really the great thing is that, heedless of question and answer alike, with a fine disregard for all extraneous considerations, men of science, men with a job to do, proceed in obedience to the universal spirit; which is a fact of faith more precious to the world than all the facts of discovery—for it must precede, it has prepared for, and it does assure the conditions that make for discovery."—W. J. CAMERON, *Ford Motor Company, from an address before the second Industrial Research Conference at The Ohio State University.*

Question and Comment

Belleville Spring Design

To the Editor:

Mr. Tatarinoff's article on Belleville washers appearing in your June number impels this writer to make a few comments on the subject of these very useful but far too little used springs.

Attention should be called to a misprint in the equation given for calculating the deflection. The logarithmic term in the bracket should have a factor of 2.3 and not 2x3. Thus it should read:

$$d = \frac{4\,P}{3\,\pi\,E t^3}\,(R^2 - r^2 + 2.3\,R\,r \log_{10} R/r)$$

$$d = \frac{4\,P}{3\,\pi\,E t^3}\,(R^2 - r^2 + R\,r \log_e R/r)$$

The same correction also applies to the last equation which, in addition, contains another misprint in the numerator, so that correctly it should read:

$$R/t \times R/d = \frac{9E\left(1 - \frac{2}{3}\frac{r}{R}\right)K}{4\,T\left[1 - \left(\frac{r}{R}\right)^2 + 2.3\,\frac{r}{R}\log_{10}\frac{R}{r}\right]}$$

The curves published on page 227 do not contain any of these errors.

The deflection equation given by Mr. Tatarinoff is that given by D. A. Gurney (*A.S.M.E. Transactions*, Vol. 51, 1929) with one important difference. According to the latter, the modulus of elasticity E for steel should have a value of 23,300,000 lb. per sq.in., whereas Mr. Tatarinoff calls for 28,500,000 lb. per sq.in. This is quite an appreciable difference and it is probably due to the different size of the springs the two investigators studied. This in itself casts doubt on the universal validity of the equation, which does not permit the use of the true modulus of elasticity of steel.

The equation has two shortcomings: first, it does not contain the dish angle or the free height of the spring, which influences to a great extent both the load carrying ability and the stress, as well as the rate of the spring. Secondly, it gives a straight line relationship of load and deflection, which in the majority of cases is incorrect and is approximated only with relatively thick springs where the order of deflection is not large, compared to the thickness. If the deflection becomes as large or larger than the thickness, the fundamental assumption that the strain in the middle surface of the spring can be neglected, becomes incorrect and the tests will show an appreciable departure from the calculated values, which will be more apparent the larger the free height and the deflection. The load-deflection curve thus approaches a cubic parabola rather than the straight line the equation indicates.

Since Mr. Gurney's paper, Almen and Laszlo have published new equations for calculating Belleville washers (*A.S.M.E. Transactions*, Vol. 58, 1936). The equations given there satisfy not only the case of thick springs with small deflections but also the cases where deflections are large compared to thickness, and thus are of far more general applicability. The correctness of the load equation has been checked in numerous instances by the authors, whereas the stress equation has been confirmed by comparing the calculated stress distribution with the one measured by Lehr and Granacher (*Forschung*, March, April, 1936).

This method of calculation gives, in general, a non-linear relationship of load and deflection, as well as stress and deflection. It also enables the designer to get any desired load-deflection curve, that is, any desired rate, by the proper choice of the ratio of thickness to free height.

Taking only thick springs with substantially straight load-deflection curves, the writer compared in several instances the above method with the one given by Mr. Tatarinoff and found the latter to give somewhat higher values than either the tests or the above mentioned equations.

More serious than this, the value of the stress as calculated by Mr. Tatarinoff's equation is much lower than the one the new method gives which, as mentioned above, is in close agreement with the actual stress. This would result in springs which will be overstressed, unless considerably higher safety factors are used than those given by Mr. Tatarinoff. His equation shows a straight linear relationship of stress and load, that is, of stress and deflection which, as mentioned above, is incorrect for larger deflections.

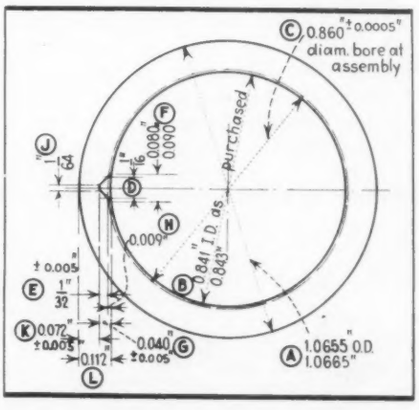
The low calculated stress also explains why the table on page 226 of comparative weights of various springs shows Belleville washers being able to absorb some 60 per cent more elastic work per pound of material than coil springs made of round stock—that is, their resiliency is 60 per cent higher. Since the resiliency varies with the square of the stress, a lower permissible stress would show very much lower resiliency. In the writer's experience, Belleville springs weigh some 30 to 50 per cent more than coil springs doing the same duty. This, however, does not detract from their usefulness in numerous applications where their peculiar advantages can be used to the full extent. These advantages are: compactness, the possibility of variable spring rates, and an easy adaptation to various designs where the washer can be called upon to act as a structural member as well as a spring. A good example of this is the 1938 Chevrolet clutch where a Belleville washer is loading the pressure plate and serves as a throwout lever at the same time.

—A. Laszlo
Research Laboratories,
General Motors Corporation

Calculating Groove Depth

ROBERT G. N. EVANS
Bunting Brass and Bronze Company

Different methods used in laying out dimensions and locating oil grooves by various engineers and draftsmen cause confusion to arise between the manufacturer of the bearing and the inspection department of the user. The finished



A simple method of designating width and depth of groove before and after final bore or ream at assembly

groove does not always have the area desired by the engineering department.

The accompanying drawing illustrates a comprehensive standard method of dimensioning that avoids confusion. The difference of *A* and *B* divided by 2 equals the wall thickness before boring the bearing in position. The difference between *A* and *C* equals the wall thickness after boring. The width of *F* is reduced to *D* after the boring operation. Depth *G* has been reduced to *E* after the boring operation. Dimension *K* remains the same, which gives the inspection department of both manufacturer and user a positive point from which comparative checks can be made. When detailing, specify dimension *F* and *K*. This will give the engineer the area he wants after boring, and all inspectors can check in the same manner. The engineer or layout man does the calculating instead of the machine operator or the inspection department. In the event no stock is to be removed from the bore, dimensions D and K are used.

Reversing Mechanism

To the Editor:

On page 186 May number of *Product Engineering* Mr. L. L. Lapayrouse inquiries about reversing mechanisms used with felt cleaner for paper making machinery.

From the description of the unit involved I gather it is a traversing motion or mechanism which imparts a reversing movement to the cleaner mentioned above, and that it is constant speed reciprocating movement with the length of the traverse constant.

For movements like this, if my interpretation is correct, there has been in use in textile machinery a device employing a revolving screw with right- and left-hand threads or grooves crossing each other and connecting at both ends in a sweeping curve. A fork-shaped follower engages this groove. The screw is located inside of a tube with a longitudinal slot through which follower projects engaging the movable member, in this case a grinding wheel. This means that the tube also is a revolving member, but can also be stationary according to requirements.

This type of reversing mechanism has been in use for many years on cotton carding machines with satisfactory results. It eliminates reversing clutches, gears, and tripping mechanisms, and may prove of interest to Mr. Lapayrouse.

—S. H. HELLAND
Whitinsville, Mass.

[Editor's Note.—The June, 1930 number of *P.E.* contained an article beginning on page 260, wherein designs of traversing or coil winder distributors were described.]

Thermal Conductivity of Beryllium Copper

To the Editor:

We have noted in the June, 1938 issue of *Product Engineering* the article by Robert W. Carson entitled "New Alloys for Springs." On Page 213 at the bottom is Table I giving the thermal conductivity for three alloys. The value for beryllium copper is incorrect. When expressed in the unit B.t.u. per sq.ft. per hr., the value is 504 to 720.

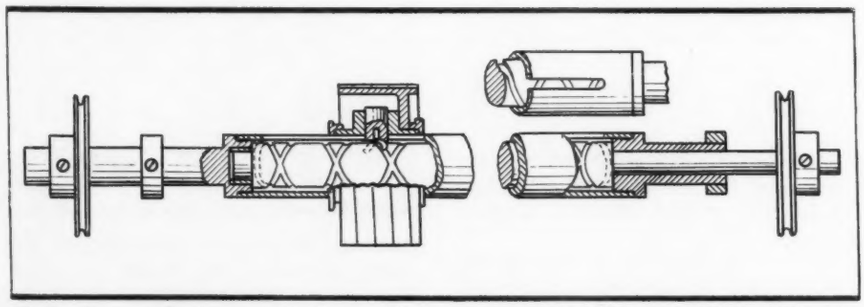
In the Anaconda booklet on beryllium copper the values for the heat treated material are given as follows:

Thermal Conductivity (hard drawn, then heat treated) 0.16 B.t.u./sq.ft./in./sec./deg. F at 68 deg. F; 0.20 cal./cm²/cm/sec./deg. C at 20 deg. C.

—C. H. DAVIS
Assistant Technical Manager
American Brass Company

To the Editor:

Mr. Davis of American Brass is correct in the comments published above. The usual value of the thermal conductivity in fully heat-treated spring temper beryllium copper does not, however, cover quite as wide a range as Mr. Davis gives. The thermal conductivity varies with both the cold work and the actual heat-treating time and temperature, but for most spring applications, the single value of 600 B.t.u. per sq.ft. per in. per hr. will be sufficiently accurate for design calculations. —R. W. CARSON
Instrument Specialties Company
Little Falls, N. J.



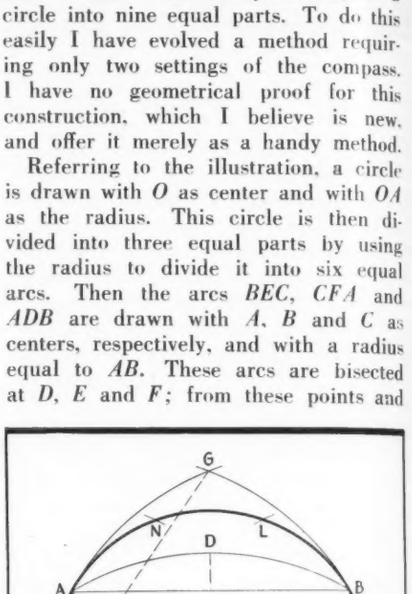
Traversing mechanism employing revolving screw with right- and left-hand threads

Division of Circle Into Nine Equal Parts

To the Editor:

On various occasions in my work I have found it necessary to divide a circle into nine equal parts. To do this easily I have evolved a method requiring only two settings of the compass. I have no geometrical proof for this construction, which I believe is new, and offer it merely as a handy method.

Referring to the illustration, a circle is drawn with *O* as center and with *OA* as the radius. This circle is then divided into three equal parts by using the radius to divide it into six equal arcs. Then the arcs *BEC*, *CFA* and *ADB* are drawn with *A*, *B* and *C* as centers, respectively, and with a radius equal to *AB*. These arcs are bisected at *D*, *E* and *F*; from these points and



Geometrical construction for division of a circle into nine equal parts

with the same radius, *AB*, arcs *HCI*, *IAG*, and *GBH* are struck. With *G*, the intersection of arcs *GH* and *GI*, as a center, and with the same radius *AB*, points *J* and *K* are marked on the circle. In the same way points *L* and *M* are obtained by using *H* as the center and *N* and *P* are obtained by using *I* as a center. Those six points together with *A*, *B* and *C* divide the circle into nine equal parts.

Possibly this will interest your readers and they may submit the proof.

—H. S. WHAREN
International Correspondence Schools

Quick-Hardening Synthetic Enamel

To the Editor:

The new synthetic enamels which "dry" by polymerization have a decided advantage over the types of nitrocellulose lacquers which have been used in the industry for several years, and

which in turn superseded the old natural resin varnishes and enamels that gave industry so much trouble by slow drying. The old automobiles using this former product frequently had to be coated and rubbed down twenty-five times before a satisfactory finish could be obtained. This entailed a period of several weeks between operations.

The polymerizing synthetic enamels, the latest development, have the property of seasoning to their ultimate hardness in the hot oven in a short period ranging from five to fifteen minutes at temperatures ranging from 300 to 400 deg. F. Many of the slow bake, low temperature ovens were not adequate for this new system of finish. Consequently, we have had to completely re-equip our plant with a newer type of oven. In these ovens, natural gas fuel is used for heating but the products of combustion do not enter the ovens. They are heated indirectly. In addition to this, we carefully wash all of the air in spray booths over a curtain or sheet of water, and all of the air entering the spray booths and ovens is carefully conditioned and filtered. Also, we reclaim on this same water curtain all of the enamel spray that does not actually deposit on the surface to be finished; and it is returned to the manufacturer for re-processing. In our product we prefer finishing after assembly, thus obviating the necessity for handling finished parts during assembly, and the result is a very much cleaner and finer looking product. Our new ovens have therefore been greatly enlarged to handle such assembly finish. Incidentally, the plant is now completely conveyerized—parts first pass through the cleaning and degreasing units, then through the Bonderizing Department, next they are automatically primed and finally pass through the synthetic enamel ovens.

Our finishing is most elaborate and complete, with the highest alkaline, water, and acid resistance it is possible to obtain on metal surfaces.

—THOMAS J. LITLE, JR.
Chief Engineer
Easy Washing Machine Corp.

Drafting Problem

To the Editor:

The drafting problem presented by Mr. Hinman in the July issue of *Product Engineering* has no geometric solution in the strict sense, since its algebraic treatment leads to an equation of the fourth degree. Of the so-called mechanical solutions available, the following is perhaps the best adapted to ordinary drafting facilities.

Draw the rectangle *B* to the given dimensions and mark its geometric center *C*. On a piece of transparent paper, draw a strip of indefinite length and of the same width as the rectangle *A* of the problem, having the square end *ed*. Mark the center-line *ab* on *A*. Now apply the transparent drawing on that of rectangle *B* and bring corners *e* and *d* tangent to adjacent sides of *B*, as shown, while center line *ab* remains through the point *C*. The distance from *e* to the intersection *f* will then be the required length *L* of rectangle *A*.

The algebraic solution is as follows:

Triangles *dge* and *ehf* are similar, and hence

$$\frac{y}{x} = \frac{5-x}{11-y}$$

$$x^2 + y^2 = 3^2 \text{ or } y = \sqrt{9-x^2}$$

$$L = \sqrt{(5-x)^2 + (11-y)^2}$$

Elimination of y gives the quadratic:

$$2x^4 - 10x^3 + 55x^2 + 45x - 504 = 0$$

Rather than to attempt a general solution of this complicated equation and then going through a mass of computation in the determination of its roots, a numerical solution aiming at the desired root should be made. Thus by the use of Newton's well-known method, the value for x can be quickly found to be

$$x = 2.943199$$

and with this value

$$y = 0.581013$$
$$L = 10.620061$$

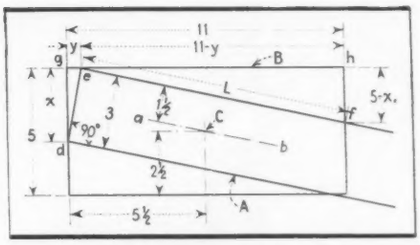
Newton's method as applied to the present case is as follows. Considering x as a continuous variable, let

$f(x) = 2x^4 - 10x^3 + 55x^2 + 45x - 504$

$f'(x) =$

$$\frac{d}{dx} f(x) = 8x^3 - 30x^2 + 110x + 45$$

and let α be the root sought, so that $f(\alpha) = 0$. From a layout, a rough value α_1 of α is obtained. Then, a more refined value α_2 of α is computed by means of the formula



$$\alpha_2 = \alpha_1 - f(\alpha_1)/f'(\alpha_1)$$

With the value α_2 thus found, a still more refined value for α is obtained by applying the formula once more; thus

$$\alpha_3 = \alpha_2 - f(\alpha_2)/f'(\alpha_2)$$

And so, by repeated applications of the formula, values of α may be obtained as accurately as desired. It is to be observed that as the values α_1, α_2, α_3 approach the true value of α, the values of $f(\alpha_1)$, $f(\alpha_2)$, $f(\alpha_3)$ approach zero, which fact may be taken as a criterion for the refinement of the successive approximations to the value of α. Usually, two applications of the formula will be sufficient to obtain highly accurate values, especially when $f''(\alpha)$ is large.

—J. J. PESQUEIRA
New York, N. Y.

[EDITOR'S NOTE.—Because of the number of replies received on this brief problem, we must confine ourselves to publishing one typical analysis and recommending a vote of thanks to those others who also sent in logical solutions: H. G. Taylor, *New York, N. Y.*; E. J. Himmelsbach, *Montreal, Canada*; W. H. Curtis, *Elyria, Ohio*; Mannious Gottlieb, *Philadelphia, Pa.*; H. A. Bowers, *Mariemont, Ohio*; J. George Thompson, *Philadelphia, Pa.*; Ernest Voyt, *Detroit, Mich.*; Hans Schemm, *Upper Darby, Pa.*; Alexis Thompson, *New York, N. Y.*; George Thyer, *Chicago, Ill.*; Michael Maletz, *Milwaukee, Wis.*; Horace N. Jones, Jr., *Batavia, Ill.*; *Product Engineering* is interested in publishing mathematical teasers. Readers are invited to submit them.]

Can You Work This One?

H. E. SMITH
Newark, N. J.

Solution to Last Month's Problem—

Aluminum and Copper Balls

The balls will have different moments of inertia, the larger moment of inertia being that of the copper ball. Thus, if they are both started rolling down an inclined plane, the aluminum ball will accelerate faster.

This Months Problem—

Storekeeper and Weights

A storekeeper has five weights, each being an exact multiple of one pound. By using a set of balance scales he can weigh out any exact multiple of a pound up to and including 121 pounds. What are the five weights?

SHEET METAL FA

Various special types of fastenings which provide vibration-proof assemblies in sheet metal construction

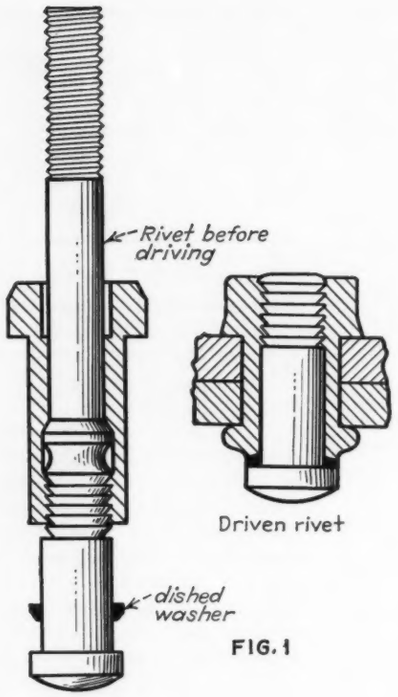


FIG. 1

Fig. 1—The Huck rivet provides a method of attachment that employs a special gun for driving. As the rivet gun is applied to the rivet, its jaws automatically engage the rivet pin pull grooves. When the trigger is depressed, oil supplied by the pressure generator moves the jaws away from the work and pulls the pin through the sleeve. The reaction to this force is taken by the anvil end of the gun against which the rivet head rests. Further travel of the pin causes the tubular rivet end to form a head on the blind side of the work, which pulls the parts together. This rivet is described more fully in *Product Engineering*, October, 1937, page 398.

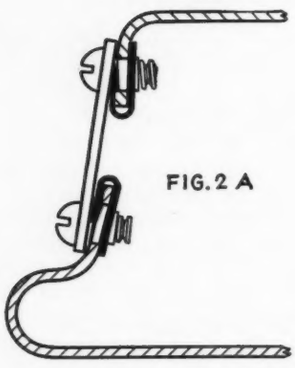


FIG. 2 A

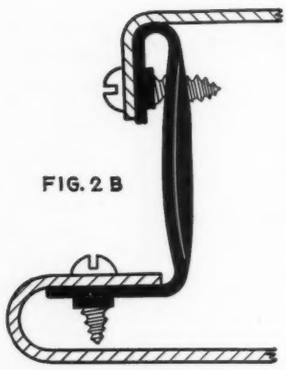


FIG. 2 B

Fig. 2—Speed Nut fasteners which replace nuts and washers hold parts together by means of spring tension and are available in spring steel, cold rolled steel, stainless steel, or phosphor bronze. These are stamped so that thread engaging means are pushed up from the bowed surface of the strip. *A.*—Three-quarter *U* in shape, this fastening is slipped over the edge of flange with lower leg snapped into register with bolt holes. *B.*—Special shaped fastening designed to provide a supporting medium as well as a connecting member for spaced assemblies. *C.*—Application of a standard Speed Nut fastening to the cover assembly of an electric switch control box. The spring tension grip permits turning of the cover for locking the cover open or closed. *D.*—U-shaped fastening used in general blind location assembly. Designed with an extruded hole in its lower leg, so that when it is slipped over the edge of the concealed assembly part, it snaps to the bolt hole to secure perfect register. *E.*—An additional application of the U-shaped fastening to cooking range door assembly. A small "Z" angle clip is welded to one member of the blind location assembly, and a U-shaped fastening is slipped over the clip which main-

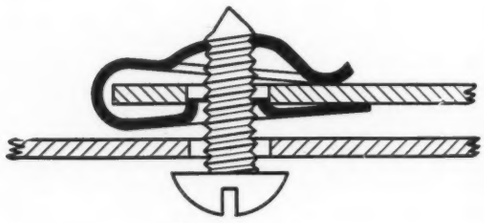


FIG. 2 D

FIG. 2 C

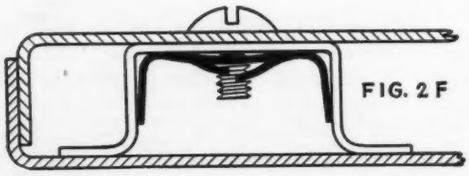


FIG. 2 F

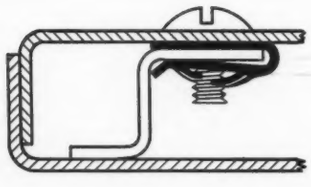


FIG. 2 E

FASTENINGS

tains itself in proper bolt receiving position under spring tension. *F.*—For hollow closures, such as electric and gas range door assemblies, this special shaped fastening is sprung into bolt receiving position and held by means of a plain metal clip welded to the door panel. *G.*—Channel shaped fastening, designed for hinged assembly of refrigerator doors, is made of spring steel and is sprung into position prior to assembly in order to serve as reinforcement for the door panel and at the same time eliminate the use and welding of tapping plates. *H.*—A shake-proof twin door hinge fastening as used in the hinged assembly of refrigerators, or heating and ventilating equipment, eliminates tapping strips and welding.

Fig. 3—Arched spring tongues form the locking action in the Palnut. As the nut is seated, the tongues are wedged tightly against bolt threads to provide a vibration-proof fastening.

Fig. 4—This snap holder, made by the Columbia Nut and Bolt Company, is self-retaining in the bolt hole, and holds the nut securely after the bolt is tightened.

Fig. 5—Two types of screws which form tight sheet metal fastenings. The Parker-Kalon hexagonal head screw is illustrated at *A*. The American sheet metal self-tapping screw, available with a Phillips Recessed Head, and illustrated at *B*, forms its own thread in the lead hole, to provide extra holding power.

Fig. 6—The Stimson screw is furnished with split prong ends which are spread after the screw is inserted.

Fig. 7—The Eaton Washer which provides binding action for bolts and screws has sharp bosses formed on an undulating surface. Locking action is provided by the engagement of the sharp bosses in the contacting surfaces, and some reactive action is supplied by the surface distortion of the washer.

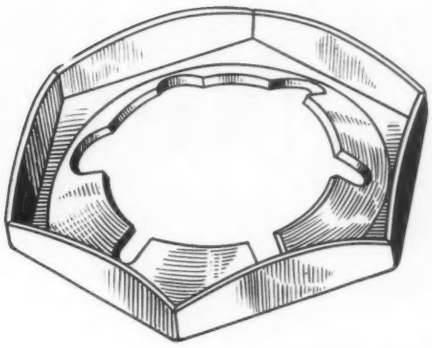


FIG. 3

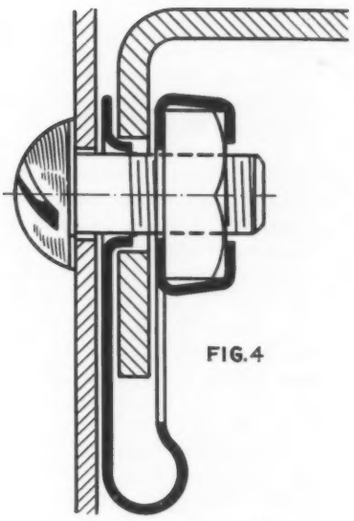
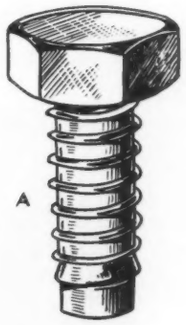


FIG. 4

FIG. 5



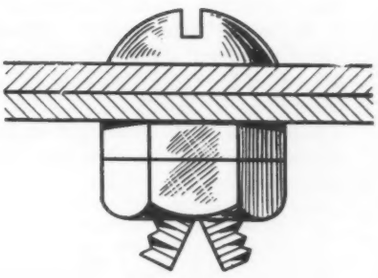


FIG. 6

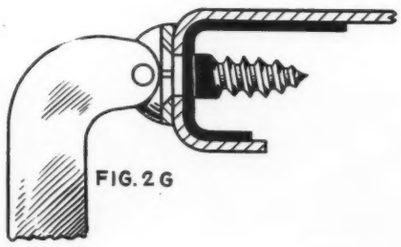


FIG. 2 G

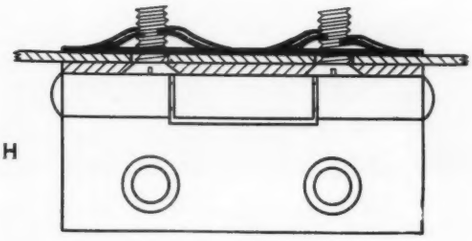


FIG. 2 H

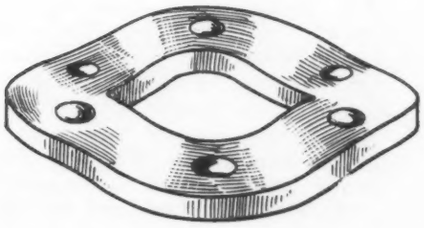


FIG. 7

News

National Metals Exposition

MORE THAN 230 exhibitors, ranging from steel and non-ferrous metal manufacturers to makers of furnaces, welding equipment and lock washers, have arranged to show to industrial buyers in Detroit at the 20th annual National Metals exposition to be held October 17-21, according to Mr. W. H. Eisenman, managing director of the exposition and national secretary of the American Society for Metals.

This exposition, one of the oldest industrial shows in the country, is staged annually in conjunction with the National Metal Congress, which is sponsored by the American Society for Metals in cooperation with the American Welding Society, the American Institute of Mining and Metallurgical Engineers, and the Wire Association. Of interest this year will be the visit of 200 members of the Iron and Steel Institute and Institute of Metals of Great Britain.

One of the features of the Metals convention will be a two-day symposium on the "Effects of Alloying Elements on the Hardenability of Medium and Low Alloy Steels." The society will also present five daily educational lectures on "Machinability" and three lectures by Mr. R. B. Sosman of the United States Steel Corporation, on "Pyrometry."

The annual feature is the Edward De Mille Campbell Memorial Lecture, delivered each year by an outstanding authority in the metal field. This year's lecturer will be A. L. Boegehold, head of the metallurgical department, General Motors Corporation, Research Laboratories Division.

Standards for Malleable Iron Fittings Revised

SUBCOMMITTEE No. 2 of the Sectional Committee on the Standardization of Pipe Flanges and Fittings has recently completed a proposed revision of the Tentative American Standards for Malleable Iron Screwed Fittings.

This revision not only includes up-to-date information on malleable iron screwed fittings but also incorporates specifications for locknuts and bushings as well as the material on pipe plugs previously published in the American Standard for Pipe Plugs, B16e2-936. This proposed revision is now being distributed to industry for criticism and comment. Copies of it are available on application. All communications should be addressed to Mr. C. B. LePage, Assistant Secretary, The American Society of Mechanical Engineers, 29 West 39th St., New York, N. Y.

Observation Car Has Polaroid Windows

THE FIRST light-conditioned railroad car, the Copper King, an observation lounge car, has been put into service on the Union Pacific streamliner, the City of Los Angeles.

The car is equipped with 29 Polaroid circular windows, 13 on each side and three in the circular car end, with one in the rear door. Each Polaroid window is 27 in. in diameter and consists of two laminated Polaroid disks, one over the other mounted in such a way that the outer disk is stationary, while the inside disk can be revolved by turning a handle or knob. Thus passengers can adjust the window brightness, conditioning the light to their own individual desires.

Copper has been used extensively for interior decoration, finishings and appointments. Side walls of the car are of satin-finish copper paneling, and furniture has copper bronze frames; tables, smoking stands and other accessories are of copper bronze, and copper is used in the construction of the car's buffet.

Interior view of "The Copper King," observation car, showing circular variable-density windows with control knobs in brass window panels

Gray Iron Technical Data Being Collected

CRITICAL study of the world's technical literature on the properties of gray iron has been started at Battelle Memorial Institute by the Gray Iron Founders' Society, Incorporated. The data gathered by the Battelle metallurgists will be presented in a form adapted to the needs of the sales and service organizations of the member foundries.

Much valuable information on the engineering properties of modern gray iron can be found in scattered technical publications, but is not usually accessible or in a convenient form for practical use. The Battelle staff will select the most useful and authoritative material and arrange it for the use of foundrymen, engineers, and purchasing agents.

Regional Foundry Conference

AT THE Second Annual Regional Foundry Conference, sponsored by the St. Louis Chapter of the American Foundrymen's Association in cooperation with the Missouri School of Mines and Metallurgy, and to be held at Rolla, Mo., October 7 and 8, papers will be presented on cupola practice, non-ferrous and malleable iron, gray iron and steel. Mr. L. E. Everett of the Key Company of East St. Louis will deliver a paper on

"Manufacture of Steel Castings for High Pressure, High Temperature Service," and Joseph D. Walsh, of the Scullin Steel Company of St. Louis will present a paper "Blow Holes in Steel Castings."

Symposium on Rubber

THE Committee on Rubber and Plastics of the American Society of Mechanical Engineers will hold a symposium on rubber at the fall meeting of the society in Providence, R.I., October 5 to 7.

The papers to be presented at this meeting will emphasize mechanical problems in the production and use of rubber and will include discussions of "The Engineering History of Rubber" by Dr. W. C. Geer of Ithaca, N. Y.; "Synthetic Substances with Rubberlike Properties," by E. R. Bridgewater of the E. I. du Pont de Nemours & Company, and on "Mechanical Characteristics of Rubber," by F. L. Haushalter of the B. F. Goodrich Company. Following the second session, A.S.M.E. members and visitors at the convention will visit the Providence plant of the U. S. Rubber Company.

Dayton Firm Acquires Wrinkle Patents

ORGANIZED to control the patents on wrinkle finishes used on radios, cash registers, typewriters and similar products, New Wrinkle, Incorporated of Dayton, Ohio has acquired the seventeen American and two Canadian patents of The Chadeloid Chemical Company, The Key and Ess Chemical Corporation and The Kay and Ess Company. These patents cover all of the irregular surface finishes generally described as wrinkle, crinkle, shrivel, and morocco which are produced with China wood oil or its equivalents, and apply to both oxidized and non-oxidized finishes. Manufacturers of such special finishes are operating at present under a revised form of license developed by New Wrinkle, Incorporated.

The primary objective of New Wrinkle, Incorporated is to create an acceptance for these types of finish as standard rather than special by developing new and wider uses. The company will rely on trade paper advertising and is contemplating the publication in book form of a comprehensive collection of technical data on these finishes.

Seventh International Management Congress

THE PROGRAM of the Seventh International Management Congress, to be held in Washington, D. C. the week of Sept. 19, contains more than 200 scheduled papers on subjects related to administration, production, distribution, personnel and agriculture. Attendance is expected to exceed 2,000 persons.

At the technical sessions, papers will be read and discussions held on Manufacturing Management; Plant Layout, Processing and Equipment; Production, Material and Quality Controls; Work Standardization and Evaluation; and Cost Methods and Accounting for Control. Ralph E. Flanders, president, Jones and Lamson Machine Company is chairman for the Production section.

Do You Know That—

A 400-hp. Morse silent chain drive, installed in 1920 at the American Wringer Company, has been operating 18 years on almost continuous 24-hour duty. (88)

* * *

A COMMERCIALLY practical process for plating on aluminum has been developed. After receiving an undercoating of nickel, the aluminum can now be plated with chromium, silver, copper or zinc. It is claimed that the new process assures a bright lustrous, easily cleaned finish, impervious to corrosion. (89)

* * *

A NEW METHOD of spraying liquid rubber on and in tanks and other containers gives a multi-ply lining securely bonded and free from air bubbles and consequent blisters. (90)

THE USE of bright nickel coating beneath gold has been found valuable in improving gold plated pieces, especially in objects where intricate and complicated designs must be covered. (91)

* * *

A NEW colloidal preparation, recently developed, is sprayed on surfaces to be protected during a paint spraying operation. After the painting or lacquering, dried accumulations may be peeled off in sheets. (92)

* * *

EIGHTY-EIGHT different kinds of nickel alloy steels have been approved by the Society of Automotive Engineers for use in passenger cars, buses and trucks, the nickel content ranging from a fraction of one per cent to 32 per cent. (93)

MEETINGS

AMERICAN SOCIETY OF MECHANICAL ENGINEERS—*Applied Mechanics and Hydraulic Division, cooperating in International Congress of Applied Mechanics to be held at Massachusetts Institute of Technology, Cambridge, Mass., Sept. 12-16. C. E. Davies, secretary, 29 W. 39th St., New York, N. Y.*

AMERICAN FOUNDRYMEN'S ASSOCIATION—*Second Fall Technical Conference, Michigan Union Building, Ann Arbor, Mich., Sept. 15-17. Further information can be obtained from Detroit A.F.A. Chapter.*

SEVENTH INTERNATIONAL MANAGEMENT CONGRESS—*Washington, D. C., Sept. 19-23. N. W. Barnes, executive secretary, 347 Madison Ave., New York, N. Y.*

SOCIETY OF AUTOMOTIVE ENGINEERS—*National Truck, Bus and Rail Car meeting, Chicago, Ill., Oct. 4—5. John A. C. Warner, secretary and general manager, 29 W. 39th St., New York, N. Y.*

AMERICAN SOCIETY OF MECHANICAL ENGINEERS—*Fall meeting, Providence, R. I., Oct. 5-7. C. E. Davies, secretary, 29 W. 39th St., New York.*

AMERICAN SOCIETY OF TOOL ENGINEERS—*Semi-annual meeting, Pittsburgh, Pa., Oct. 14-15. Further information may be obtained from Ford R. Lamb, executive secretary, 2567 W. Grand Boulevard, Detroit, Mich.*

PORCELAIN ENAMEL INSTITUTE—*Eighth annual meeting, Cleveland, Ohio, Oct. 25-26. Further information may be obtained from the Institute at 612 N. Michigan Ave., Chicago, Ill.*

EXPOSITIONS

ASSOCIATION OF IRON AND STEEL ENGINEERS—*Iron and Steel Exposition—Public Auditorium, Cleveland, Ohio, Sept. 27-30. Further information may be obtained from headquarters at the Empire Bldg., Pittsburgh, Pa.*

NATIONAL METAL CONGRESS AND EXHIBITION—*Convention Hall, Detroit, Mich., under the auspices of the American Society for Metals, Oct. 17-21. Further information can be obtained by communicating with W. H. Eisenman, secretary, 7016 Euclid Ave., Cleveland.*

NATIONAL AUTOMOBILE SHOW—*Grand Central Palace, New York, N. Y., Nov. 11-19, under the auspices of the Automobile Manufacturers Association, 366 Madison Ave., New York, N. Y.*

THIRTEENTH NATIONAL EXPOSITION OF POWER AND MECHANICAL ENGINEERING—*Grand Central Palace, New York, N. Y., December 5-10. Further details can be obtained from Charles F. Roth, president of the International Exposition Co., Grand Central Palace, New York, N. Y.*

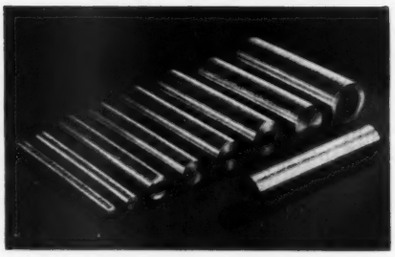
New Materials and Parts

Improved Parkerizing

In this new Parkerizing process, the processing time has been reduced to about a third of that formerly required. Instead of 60 to 90 minutes the processing time is now 30 minutes. Another feature is the reduction of operating temperature from 210 deg. F. to 180 deg. F. resulting in lower heating cost. These new chemicals are also said to develop less sludge in the processing tank and to produce a finer grained, smoother coating. This last is important on articles where close tolerances must be maintained. The size and cost of the processing tanks is correspondingly reduced. Parker Rust-Proof Co., 2179 E. Milwaukee Ave., Detroit, Mich.

Sterilamps

A new line of equipment for use in "Rentschlerizing," a means of sterilizing through the use of selected ultra-violet radiations produced by Sterilamps. The lamps are slender rod-shaped glass tubes with effective lengths of 10, 20 or 30 in. Two types of fixtures are available, the SB-30 for ceiling or wall mounting, equipped with a flat Alzac-finished aluminum reflector. The SC-30 fixture is especially designed for refrigerated display cases and shelves. Both types are complete with sockets, terminal boxes and necessary hardware for mounting. A special power unit is used for energizing the tubes. It is said that more than 80 per cent of the radiant energy produced by the Sterilamp is in the region of 2550 Angstroms which provides the most effective bactericidal energy. Power unit for operating Sterilamps consists of a transformer, relay, starting button and safety door switch, all inclosed in a neat metal housing. Westinghouse Electric & Mfg. Co., Lamp Div., East Pittsburgh, Pa.



Bronze Bars

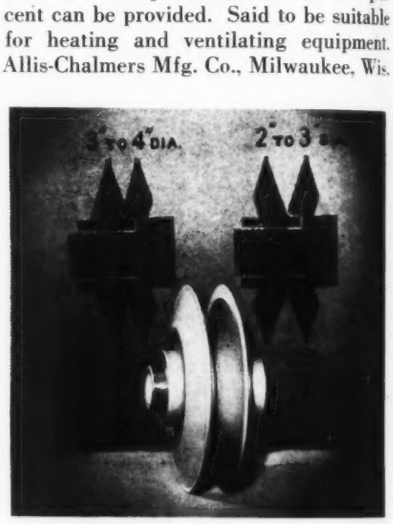
A new line of cored and solid bronze bars to be known as "Bunting Precision Bronze Bars." The material used is known as Bunting No. 72 and also SAE 660, developed to provide an alloy that would have ample strength to resist heavy loads and perform satisfactorily under many different adverse operating conditions and at the same time embody exceptional anti-frictional qualities giving long life and minimum wear. Alloy is composed of 83 per cent copper, 7 per cent tin, 7 per cent lead, and 3 per cent zinc. The bars are supplied completely finished in 13 in. lengths with the finished size to which a piece may be machined, stamped along the entire length of the bar. The Bunting Brass & Bronze Co., Toledo, Ohio.

Weld Cleaning Compound

A new compound said to reduce cleaning time after welding by 20 to 60 per cent. Known as "Spatter Film," the compound reduces the tendency of spatter to adhere, thus facilitating its removal. "Spatter Film" is soluble in water, is non-inflammable and contains no free alkali to injure the hands or harm paint. Applied by means of an ordinary paint brush and only sufficient of the film need be applied to cover the work adjacent to the seam or joint. A gallon will cover approximately 50,000 sq. in. of surface. Wiping with a clean cloth or washing it off with water removes the spatter film. The Lincoln Electric Co., Cleveland, Ohio.

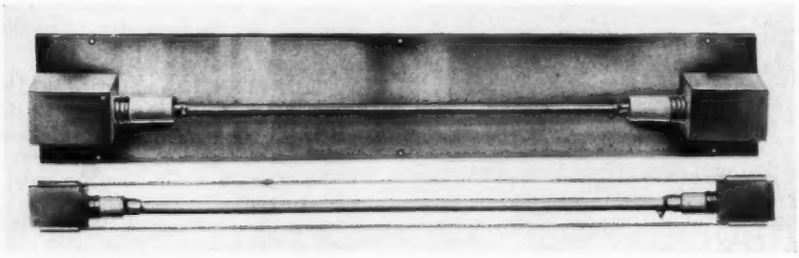
Adjustable Sheave

A new design of variable pitch sheave wherein the range of pitch diameter may be varied by removing the adjustable plate, reversing it, and replacing it on the hub. For one position the pitch diameter range can be varied between two and three inches while in the reversed position the pitch diameter can be adjusted between three and four inches. Thus a total speed variation of 100 per cent can be provided. Said to be suitable for heating and ventilating equipment. Allis-Chalmers Mfg. Co., Milwaukee, Wis.



Thermo-Setting Compound

A new thermo-setting compound, No. 1962, designed to meet problems where large metal inserts in the molded piece experience expansion and contraction because of extreme temperature changes. Possesses adequate flexibility plus the additional characteristic of stability, and is particularly applicable in the molding of compound inside a metal flange. The inherent non-shrink qualities of this new material prevent the initial shrinkage of the compound thereby eliminating future stresses which might result in cracking. Another material announced is 1040 arc-resisting compound, used principally in magnetos and other high-potential insulating parts on airplane electrical systems. Makalot Corp., 262 Washington St., Boston, Mass.

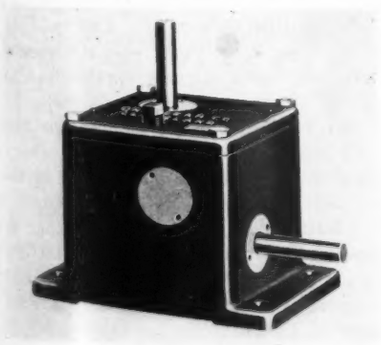


Glass Testing Polariscope

Designed to specifications set by the Testing Committee of the Glass Container Association, this new polariscopic strain tester offers a simple means of detecting strains in glass containers and glass products of all kinds. The operator views the test objects through a binocular eye piece against a powerful light source. The field is 10 in. in diameter, accommodating containers up to one-gallon size. Smaller sizes can be viewed simultaneously for comparison, and larger pieces can be inspected one part at a time. Strains appear in brilliant colors and with the use of the Polaroid strain testing spectacles, several observers can view an object at the same time. The machine is water-proof, shock-proof, and dust-proof. The entire polarizing assembly is protected from breakage by a thick sheet of unbreakable transparent plastic, and mounted in shock absorbing gaskets. The Polaroid Corp., 104 Columbus Ave., Boston, Mass.

Double Speed Reducer

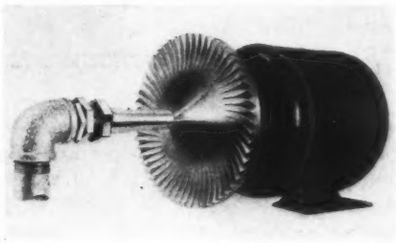
A small, vertical double speed reducer, known as VOO, for use where space is at a premium. Input and output shafts are at right angles in either the horizontal or vertical plane. A variety of locations for the input and output shafts is possible without changing the mounted position of the gear box. All gears are of SAE 65 (British Gear) bronze. Either ball or Timken bearings are available.



Dimensions of the unit are 4½x4½x4½ in. Torque capacity for units with ratio of 100 to 1 up to ratio of 800 to 1 is 100 in.-lb. For ratio of 1,600 to 1, torque capacity is 25 in.-lb. Ohio Gear Co., 1333 E. 179th St., Cleveland, Ohio.

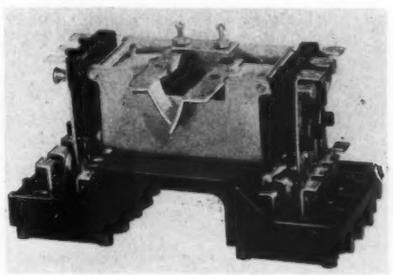
Spray Wheel

One-piece spray wheel mounted directly on splash-proof, totally-inclosed type motor. Jet of water impinging on center of wheel is transformed into spray. Changes in spray form and angle are easily made. One of the principal advantages is that the spray wheel cannot become clogged regardless of dust, lint or foreign material in the water. The spray is steady and uniform and only low water pressure is required in the jet. The wheel is made of metal or alloy to meet respective chemical or corrosive conditions existing. There are no separate pins or parts. Made in a range of sizes for capacities ranging from 10 to 150 gal. per min. D. J. Murray Mfg. Co., Wausau, Wis.



Twin-Latch Relay

A new standardized twin-latch relay which controls heavy loads with low-current drain. It carries loads up to 30 amp. a.c. or 10 amp. d.c. but requires only 8 watts for operation. It is especially suited for use in 3-wire thermostatic control system or similar circuits. It is also adopted to operations where



circuits are closed with extremely light pressure, or with slow movement. Its use is claimed to improve the operation of any single-pole double-throw control. Type L unit meets electrical code requirements up to 250 volts. Overall size is 5⅜x2⅞x2⅞ in. high. G-M Laboratories, Inc., Dept. NR, 1731 Belmont, Chicago, Ill.

Air-Cooled Gas Engine

A new 4-cycle, air-cooled gasoline motor, known as Model IBP. Actual horsepower over the recommended operating range is 0.93 at 2,600 r.p.m., 1.00 at 3,000 r.p.m., and 0.98 at 3,200 r.p.m. Piston displacement is 4.71 cu. in. with a 2 in. x 1½ in. bore and stroke. Ignition is supplied by a specially designed dust and moisture proof high tension flywheel magneto. Exhaust valves are Silchrome and their seats are alloy steel inserts; valve guides are moly steel, cylinder heads aluminum alloy. Crankshaft is drop forged, mounted on

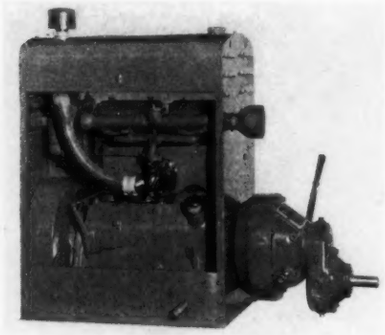
ball bearings with oil seals. Other equipment includes adjustable pneumatic governor, float feed carburetor, air cleaner, and gasoline filter. Fuel tank is 1½ gal. and oil reservoir is 1½ pints. Overall dimensions are height 14 in., width 10½ in. and depth 11 in. Net weight is 38 lb. Briggs & Stratton Corp., Milwaukee, Wis.

Chrome Lacquer

Whereas the usual synthetic lacquers when used in the clear form are attacked by ultra-violet rays, this new lacquer which was developed primarily for protecting electroplated or polished metal surfaces, is exceptionally resistant to the action of ultra-violet light. Its other outstanding characteristics are its exceptional transparency, adherence to metals, quick drying properties and its durability. When applied to metal it dries in about 15 minutes. The base of this lacquer is the same as the synthetic material Lucite. Chemically it is a methacrylate lacquer. The finish is also resistant to all usual acids and alkalies, salt spray and moisture. After eight months' exposure in Florida, panels protected with this lacquer were still in excellent condition. Before applying the protective lacquer it is highly important that the metal surface be thoroughly cleaned. E. I. du Pont de Nemours & Co., Wilmington, Del.

Air-Cooled Engine

Known as the Model AP4, this new 30 hp. four cylinder air-cooled gas engine is identical with the recently announced 25 hp. Model AM4 except that it has a larger bore. Complete with accessories both engines weigh only 340 lb. They have Timken roller bearings on crankshaft front and rear, valve seat inserts, cylinder block and crankcase cast separately for economical servicing. There are no grease cups or oil fittings as all parts are automatically lubricated from the oiling system. Air cleaners are available. Illustration



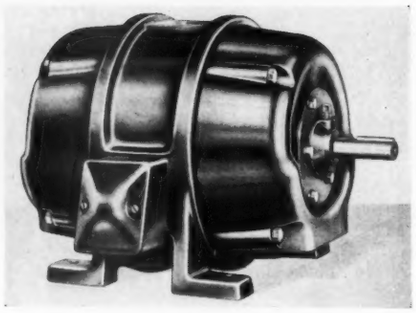
shows it as a power unit equipped with clutch and reduction gear. The AM4 has 3½ in. bore, 4 in. stroke, 154 cu. in. displacement and develops 21 hp. at 1,200, 27 hp. at 1,600, 30 hp. at 1,800 and 31 hp. at 2,200 r.p.m. The AP4 has 3¼ in. bore, 4 in. stroke, 132 cu. in. displacement and develops 16 hp. at 1,200, 22 hp. at 1,600, 25 hp. at 1,800, 28 hp. at 2,400 r.p.m. Wisconsin Motor Corp., Milwaukee, Wis.

Magnet Wire

A new magnet wire, insulated with fiber glass, has been announced as an addition to the present line of Deltabeston asbestos-insulated magnet wire. Available in round, square and rectangular shapes. General Electric Co., Bridgeport, Conn.

Thread-Cutting Screws

Known as the "Hi-Hook" thread-cutting screw, developed for plastic materials. A specially designed double-width slot gives an acute cutting edge that cuts a clean, sharp thread in all types of plastic compositions, both molded and laminated. This construction materially reduces the high driving torque normally encountered and enables fast, easy driving with a minimum of breakage. The only requirement is that the screw be inserted in a molded or drilled hole of the proper size. Shakeproof Lock Washer Co., 2549 N. Keeler Ave., Chicago, Ill.



Splash-Proof Motors

A new line line of splash-proof motors, incorporating the following design features: sturdy cast iron construction; specially impregnated windings; effective baffling system to prevent entrance of water or falling particles; improved system of ventilation to assure low temperature rise; sealed ball bearings accessible for lubrication in all mounting positions. The motors conform to NEMA specifications and are furnished in all NEMA sizes and ratings. Diehl Mfg. Co., Elizabethport, N. J.

Stainless Steel Instruments

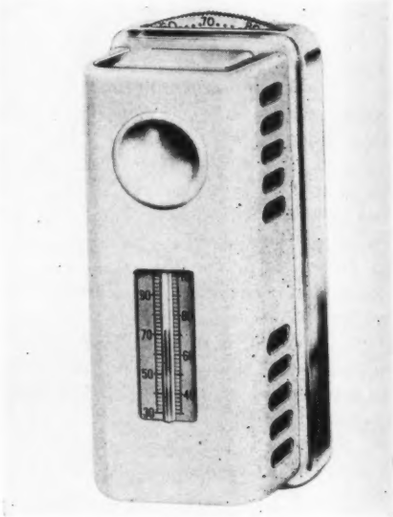
A line of vernier calipers, protractors and rulers made of stainless steel for protection against rusting and warping, and especially recommended for use in damp atmospheres or in places where acid is used. They withstand constant handling, as perspiration has no effect on the graduations or on the smoothness of the contact surfaces. The stainless steel rule and protractor illustrated is operated with the aid of dividers. A spring tension in the joint is sufficient to hold the angular setting of the blades for scribing and layout work. George Scherr Co., 126 Lafayette St., New York, N. Y.

Finish

A one-fire finish, using PEMCO V-134 frit, developed to give a low-cost finish of a more durable character for inexpensive merchandise. Has a good luster, is attractive in appearance, can be sprayed over the bisque ground coat, and is obtainable in one-fire. The Porcelain Enamel & Mfg. Co., 5106 Eastern Ave., Baltimore, Md.

Line Voltage Room Thermostat

Available for heating or cooling service, with or without the thermometer. Range on heating types is 55 to 85 deg. F. and on cooling types 65 to 95 deg. F. Switch has a load capacity of 1½ hp. 120 or 240 volts a.c., and 30 amp. 120 volts a.c., 15 amp. 240 volts a.c., but is suitable for use on low voltage. Thermostat is available in ivory and chromium or black and chromium finish, and may be mounted on a standard 3x2 in. outlet box. It is also obtainable with locked cover and tamper-proof adjustment. The White-Rodgers Electric Co., St. Louis, Mo.



Herculoy Bolts

A full line of standard sizes of Herculoy bolts and nuts especially applicable for pole line hardware, electrical and railroad equipment, marine applications, chemical, oil refining and other allied industries, where great strength in combination with high resistance to corrosion is required. Descriptive book and price list available. Revere Copper and Brass, Inc., 230 Park Ave., New York, N. Y.

Leather Packing

Treated by an exclusive process, Bitan leather packings will operate successfully against extreme pressures and under severe service conditions. The Bitan leather is said to be the most resistant to temperature and acid or alkaline solutions and is not surface treated to conceal defects inherent in the leather from which the packings are made. The packings are manufactured in all types of forms for which leather commonly is used. The Garlock Packing Co., Palmyra, N. Y.

Gage Glass

Greater visibility, greater ease of illumination and greater safety are claimed for this new "Pyrex" broad red line gage glass. It differs from previous types in that the red stripe is transparent, is proportioned to the diameter of the tube, and is fused permanently to the wall of the gage glass. A small slotted illuminator placed directly back of the gage glass produces brilliant visibility under all conditions without glare. Proportioning the width of the stripe to the tube diameter makes the entire tube appear red below the water line. The new glass is made in lengths to 24 in. and diameters ½ to 1 in. inclusive. Corning Glass Works, Corning, N. Y.

Magnetic Contactors

Bulletin No. 9560, NEMA size 0 a.c. magnetic contactors for small continuous duty single and polyphase motors. Long life of the silver-to-silver butt-type contacts is guaranteed by the manufacturer because their "twin-break" function reduces the arc and operation in a restricted pocket cools it. All moving parts are pivoted and the self-aligning armature eliminates sliding friction, allows close guiding of the contact structure, insures proper alignment and good contact pressure, maintains quiet operation which is additionally aided by rubber mounting. Available in 2-, 3- and 4-pole constructions with maximum ratings of 1½ hp. for single and 2 hp. for polyphase. It can also be secured in skeleton form for built-in use. Cutler-Hammer, Inc., 296 N. 12th St., Milwaukee, Wis.

Automatic Time Switch

An improved automatic time switch, Type TSA-14, for use in a wide variety of applications such as process timing and sign flashing, having an all-glass cover to facilitate easy inspection. The contact-making mechanism is driven

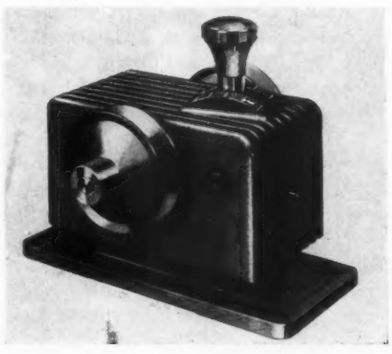
through the spur gear train by a Telechron motor. The dial of the instrument is marked in "per cent of total time." The percentage of "on" time may be varied by the user merely by rotating the dial until the desired percentage of "on" time is indicated by the pointer. Silver contacts, rated 10 amp. at 230 volts, are mounted on the brushes which bear on rotating cams. For circuits having higher ratings a suitable relay should be used in conjunction with this timer. Special switches of this type can be furnished to meet unusual performance. General Electric Co., Schenectady, N. Y.

Glass Fabric Laminated Phenolic

In place of the usual paper or fabric base, this material uses a woven glass fabric. Tests show that glass gives a low moisture absorption which has not been duplicated previously in laminated phenolic resinoid materials. Other advantages reported are a minimum change in electrical characteristics and greater resistance to the action of corrosive liquids. Synthane Corp., Oaks, Pa.

Variable-Speed Transmission

Using only standard V-belts, this inexpensive "Select-O-Speed" transmission is said to give an infinite selection of speeds over a 5 to 1 or greater ratio by a simple movement of a control lever. Its compact construction and light weight



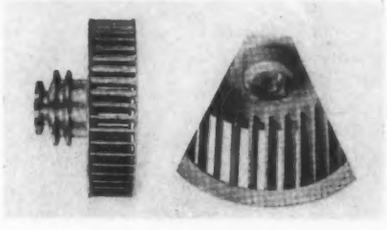
make for easy installation. It may be mounted on the floor, wall, ceiling, upside-down or right-side up and operates without noise or vibration in any position. Available in several sizes up to 7½ hp. Ideal Commutator Dresser Co., 1446 Park Ave., Sycamore, Ill.

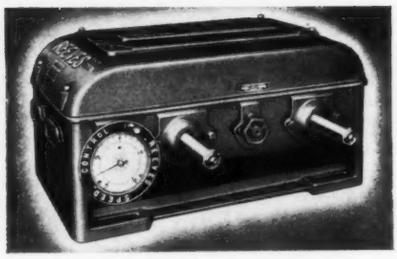
Split-Phase Motor

A line of permanent, split-phase, induction type motors, mainly suited to fan or blower service or similar low starting torque service. It is essentially a shaded pole design, the starting winding being permanently connected to the running winding. By means of a tapped choke or resistor several different operating speeds can be provided. The motors are available in sizes from 1/20 to 1/6 hp., operating on 110 volt, 60 cycle, a.c. only. Reynolds Electric Co., 2650 W. Congress St., Chicago, Ill.

Aluminum Fan Wheel

A new type blower fan with the hub cast to form the driven unit of a flexible coupling, marketed under the trade name "Castalu." The fan is cast in one piece of light-weight aluminum, assuring long life and trouble-free service. The fan is accurately balanced, bored and reamed for shaft, drilled, tapped and fitted with setscrew. Due to its lightness it is free from vibration and requires minimum power for starting and operation. The method of casting permits the maximum number of blades that insures a continuous and noiseless flow of air. The fans operate either clockwise or counter-clockwise, and are available in all standard sizes from 3x1½ in. to 10½x5¼ in. and bored to suit any shaft. Also can be obtained in special sizes as specified. Advance Aluminum Castings Corp., 2742 W. 36th Place, Chicago, Ill.





Speed Indicator

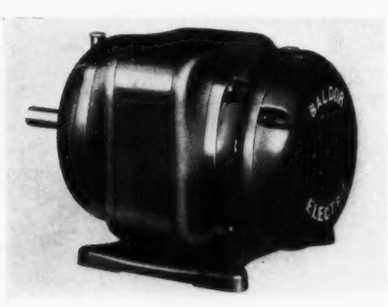
A "Speedial" handwheel for use with Reeves variable-speed control equipment, which accurately registers speed settings of the units. The actual indication is a definite number of turns, and fractions of turns, of the shifting screw. These are read by the operator as he turns the Speedial. While the standard Speedial is calibrated in turns of the shifting screw, space is available on the dial for the user to write in his own calibrations in whatever corresponding units he prefers. Where the nature of the installation requires the additional protection, the Speedial may be sealed watertight. Reeves Pulley Co., Columbus, Ind.

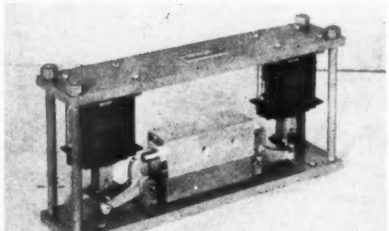
Impregnating Resin

This solution, 278, of specially formulated resin is for increasing the density of certain types of castings. Proper impregnation is made by pressure or vacuum and pressure. After impregnation the casting is baked at 250 deg. F. or higher to set the resin. When hardened in this way the resin is practically unaffected by water, solvents, mild alkalies and acids. The treatment is costly, but is of particular advantage where expensive castings have developed porosity after machining. General Plastics, Inc., Walck Road, North Tonawanda, N. Y.

Glass-Insulated Motors

By the use of glass as insulating material, plus the advantage of Streamcooled design, lighter weight, compactness and high efficiency are claimed for these new motors. They are cooled by means of an outer fan blowing a stream of air directed over the outside of the exposed laminations, greatly accelerating the high natural radiating capacity of the motor. The glass insulation material withstands high temperatures, is strong and non-absorbent, is fireproof and will not decay. Available in eight sizes from 1½ to 20 hp. in 3-phase, 220/440 volt, 60 cycle, 4 pole, 1,725 r.p.m. motors of Class "B" insulation and the new Streamcooled design, 75 deg. C. Baldor Electric Co., 4400 Duncan Ave., St. Louis, Mo.





Air Control Valve

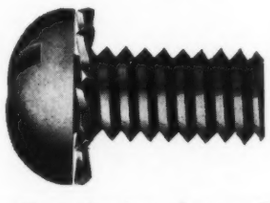
A new four-way, double solenoid, high-speed air control valve for ⅛ in. I.P.S. only and suitable for air pressures up to 200 lb. for operating cylinders whose diameters do not exceed 3 in. with correspondingly short strokes. Operates on G.E. 290-D solenoids with low amperage characteristics, employs no springs. The valving units without solenoids and assembly are available to users who desire to develop their own methods of operation. C. B. Hunt & Son, Salem, Ohio.

Automatic Timer

No. 82 Series timer, available in timing ranges of from 2 hours to the cycle up to and including 11 hours maximum, with single or double throw switch capacities of 3 amp. or 15 amp., a. c. and d. c. No winding of the clock movement is required as the turning of the pointer to the interval desired provides the operating power, sets the switch circuit and starts the timing mechanism simultaneously. Overall diameter of timer and mounting ring is 4½ in., actual dial diameter 3 in. Panel opening required 3⅜ in. diameter. At present the unit is offered for standard equipment installation only. Walser Automatic Timer Co., 420 Lexington Ave., New York, N. Y.

New Fastening Unit

A pre-assembled lock washer and standard machine screw, known as SEMS. Each screw is equipped with the correct size of lock washer for its particular type of head, and as the lock washer cannot drop off, no screw can be applied without having a lock washer under the head. The unit is claimed to have effected not only immediate cost savings, but faster and better production in preliminary tests in both large and small production plants. Descriptive literature available. Shakeproof Lock Washer Co., 2549 N. Keeler Ave., Chicago, Ill.



Vitreous-Enameled Rheostat

A new 225 watt rheostat, Model P, employing the all-porcelain and metal type of construction. The resistance wire is accurately wound on a solid porcelain core, and is rigidly held in place, insulated and permanently protected by Ohmite vitreous enamel. Capable of standing up under heat and humidity, shock and vibration, Model P is claimed to provide practically stepless resistance variation and gives smooth, close control. It has 2⅛ in. mounting depth, is 5 in. diam. and has 3¼ in. diam. molded plastic handwheel. Available in 25, 50, 100, 150, 225, 300, 500, and 1,000 watt models in a wide range of resistance values. They may be had in single or tandem assemblies. Rheostat cages can be furnished if desired. Ohmite Mfg. Co., 4835 W. Flournoy St., Chicago, Ill.

Manufacturers' Publications

AMERCOAT—American Concrete & Steel Pipe Co., Box 1428, Arcade Station, Los Angeles, Calif. "Amercoat on Guard Against Corrosion," 16 pages, 8½x11 in. Describing the various types of Amercoat cold-applied coatings, their uses, and application procedure.

CHECK VALVES—Crane Co., 836 S. Michigan Ave., Chicago, Ill. "Checking Up on Check Valves," 8 pages, 8½x11 in. Describing the two basic types of check valves and their various applications, suggestions for proper selection, and cross-section views prepared as a reference guide.

COATED COVER GLASS—Mine Safety Appliances Co., Braddock, Thomas & Meade Sts., Pittsburgh, Pa. Bulletin CE-5. Describing their M.S.A. coated cover glass and its advantages over plain cover glass.

CONTROL INSTRUMENTS—The Brown Instrument Co., Wayne & Roberts Aves., Philadelphia, Pa. Folder 89-9, 6 pages, 8½x11 in. Data on Brown air-operated controllers for temperatures, pressures, flows and liquid levels. Includes a representative list of some 50 applications of the controllers. A number of installations are illustrated.

CONTROL INSTRUMENTS—The Foxboro Co., Foxboro, Mass. Bulletin 184-2, "Rotax Electric-Operated Controllers," 32 pages, 8½x11 in. Describes Foxboro electrically-operated control instruments for applications where "open and shut" or two-position control is desired. Over 60 illustrations and diagrams are used to show installations and applications of Rotax controllers.

COORDINATED PROCESS CONTROL—The Bristol Co., Waterbury, Conn. Bulletin 551. Showing installations using Bristol's system of coordinated process control, giving a few outstanding features about the operating results of each application.

ENGINE—Waukesha Motor Co., Waukesha, Wis. Bulletin 978-G. Four page folder on the "6-BKH" Waukesha-Hesselman oil engine with improved fuel pump which permits low idling speeds.

FCC PRODUCTS AND SERVICES—The Forging & Casting Corp., Ferndale (Detroit), Mich. Spiral bound booklet, 64 pages, 5½x7¾ in. Contains illustrations and descriptions of FCC special products, including forgings, composite steel die sections, nitri-cast-iron, cast to shape tool steel, etc. Also contains tables of weights, analyses, decimal equivalents and other reference material.

FIBER—The Fiberloid Corp., Indian Orchard, Mass. Folder describing different types of plastic materials manufactured by the company, including Fibestos, Fiberloid, Fiberlon and Fiberlac.

FLAME CUTTING SERVICE—Joseph T. Ryerson & Son, Inc., Box 8000A, Chicago, Ill. Bulletin, 4 pages, 8½x11 in. Showing the wide range of products burned from rolled steel plates by modern flame cutting methods.

HIGH TENSILE STEELS—Carnegie-Illinois Steel Corp., 434 Fifth Ave., Pittsburgh, Pa. Technical information of particular interest to engineers, concerning applications, advantages and fabrication of U.S.S. high tensile steels. Chemical compositions, physical properties and similar data are included.

LIGHTING—The Fostoria Pressed Steel Corp., Fostoria, Ohio. Catalog M.L.11, 6 pages, 8½x10 in. Illustrating and describing various canopy type models of Fostoria fixtures.

LUBRICATION—Rivett Lathe & Grinder, Inc., Brighton, Boston, Mass. Bulletin B 30. 12 pages, 8½x11 in. Describing a Pulsator system of automatic oil lubrication including pumps and feeders.

MANGANESE STEEL BARS—American Manganese Steel Div., American Brake Shoe & Foundry Co., 389 East 14th St., Chicago Heights, Ill. Folder, 8½x11 in. Data and price list covering Amsco manganese steel dipper tooth repointers and filler bars.

METAL CUTTING TOOLS—Haynes Stellite Co., Kokomo, Ind. "Haynes Stellite-2400 Metal Cutting Tools." An illustrated folder describing the new high-production metal cutting alloy, Haynes Stellite-2400.

MOLYBDENUM STEELS — Climax Molybdenum Co., 500 Fifth Ave., New York, N. Y. Loose-leaf booklet, 115 pages, 10¼x11¾ in. A compilation of the most useful data on all types of molybdenum steels, both wrought and cast. The book is divided into sections, one section being devoted to each type of steel. In addition there are sections on steels for particular service such as high temperature and corrosion resisting. A complete index adds to the convenience of the book.

MOTORS—Burke Electric Co., Erie, Pa. Bulletin, 6 pages, 8½x11 in. Illustrations and data on their polyphase induction motors, including a new pivot-mounted, self-adjusting motor.

MOTORS—Harnischfeger Corp., 4400 W. National Ave., Milwaukee, Wis. Bulletin M-2, "P&H Convertible Slip Ring Motors," 8 pages, 8½x11 in. Various types are illustrated together with details of their construction.

MUREX ELECTRODES—Metal & Thermit Corp., 120 Broadway, New York, N. Y. Booklet 3a, 34 pages, 3¼x6 in. A revised booklet on Murex welding rods, containing brief data on the physical properties and chemical analysis of the weld metal deposited by each of the twenty electrodes in the Murex line.

PORTABLE CURRENT TRANSFORMERS—Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa. Catalog Section 43-137, 4 pages. Data, details of construction and operation, and applications of Type PC-137 portable current transformers for general portable service where maximum accuracy and breadth of operating range are required.

RHEOSTATS—Ohmite Mfg. Co., 4835 W. Flournoy St., Chicago, Ill. Catalog 17. Listing and describing the Ohmite line of rheostats and resistance units for the industrial, radio and electronic fields. Numerous useful tables to assist in proper selection are included.

SHALLCROSS INSTRUMENTS—Shallcross Mfg. Co., 10 Jackson Ave., Collingdale, Pa. Bulletin 140, 4 pages, 8½x11 in. Illustrations and brief descriptions of a number of the instruments manufactured by the company, together with a list of the standard size Shallcross wire wound resistors. .

STEEL CASTINGS—National Erie Corp., Erie, Pa. Booklet, 24 pages, 8½x11 in. Describing the type of steel castings made by this company, including their Neloy castings.

TANTALUM CARBIDE TOOLS—Vascoloy-Ramet Corp., North Chicago, Ill. Booklet, 12 pages, 8½x11 in. Latest catalog and price list of Vascoloy-Ramet standard tantalum carbide tools and blanks.

THERMIT WELDING—Metal & Thermit Corp. 120 Broadway, New York, N. Y. Booklet 18c, 34 pages, 8½x11 in. A comprehensive booklet, well illustrated, describing the Thermit welding process and its applications.

TIME SWITCHES—General Electric Co., Schenectady, N. Y. Folder, GEA-2963. Data on their Type TSA-14 automatic time switches for control of a.c. or d.c. circuits.

TOOL STEELS—The Kloster Steel Corp., Justine & Fulton Sts., Chicago, Ill. Folders, 8½x11 in. Four new bulletins: "Swed-Oil," a manganese-chromium-tungsten steel that is oil hardening and non-shrinking; "Hi-Run," a high chrome-high carbon production steel; "D-C-33," a low carbon-chrome-silicon-tungsten-molybdenum steel; "D-C-66," a chrome-tungsten-vanadium hot work steel which resembles a high-speed steel in its properties.

"TRUMBULLIST"—The Trumbull Electric Mfg. Co., Plainville, Conn. July 1938 edition. A complete listing of their equipment including safety switches, service equipment, multi-breakers and magnetic starters.

VARIABLE-SPEED CONTROLS—Reeves Pulley Co., Columbus, Ind. Booklet, 124 pages, 8½x11 in. Covering the complete line of Reeves variable-speed control equipment, all three of the different types of control units manufactured by this company being included in the volume. Complete with tables and dimensional drawings.

VOLTAGE TRANSFORMERS — Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa. Leaflet 43-131. Describing Type PV-130 portable voltage transformers designed for use with Westinghouse portable instruments and recorders.

WASHERS—Wrought Washer Mfg. Co., 2100 S. Bay St., Milwaukee, Wis. Stock List No. 55-B. An extensive listing of specifications for standard and special washers in various materials.

WELDING ALUMINUM—Aluminum Company of America, Pittsburgh, Pa. "Welding Aluminum and Its Alloys," 48 pages, 5½x8¼ in. A revised edition of their booklet on welding aluminum covering fusion welding, welded aluminum vessels, torch welding heat-treated aluminum alloys, welding castings, arc welding and resistance welding.

Stresses in Pressure Vessels—I

RAYMOND J. ROARK

Professor of Mechanics University of Wisconsin

THIS discussion and the accompanying formulas apply to any vessel which has the form of a figure of revolution. For convenience of reference, a line representing the intersection of the wall and a plane containing the axis of revolution is called a meridian, and a line representing the intersection of the wall and a plane normal to the axis of revolution is called a circumference. Obviously the meridian through any point is normal to the circumference through that point.

When a vessel of the type under consideration is subjected to internal pressure, stresses are set up in the walls. The state of stress is triaxial; at any point there is a meridional stress s_1 acting parallel to the meridian, a hoop stress s_2 acting parallel to the circumference, and a radial stress s_3. If the walls are relatively thin (thickness less than about one-tenth the radius) and have no abrupt changes in thickness, slope, or curvature, the stresses s_1 and s_2 are practically uniform throughout the thickness of the wall, and are the only stresses of importance present, s_3 and such bending stresses as may occur being negligibly small. The meridional stress s_1 and the hoop stress s_2 are called *membrane* or *diaphragm* stresses.

An abrupt change in thickness, or in meridional slope or curvature at any circumference in a thin vessel will cause bending and shear along that circumference and along circumferences adjacent thereto. The stresses due to this bending and shear are called discontinuity stresses; they are superposed upon the membrane stresses and comprise: (1) the meridional bending stress s_1', which varies linearly throughout the thickness of the wall; (2) an additional hoop stress s_2'', uniform throughout the thickness of the wall; (3) a circumferential or hoop bending stress s_2', which varies linearly throughout the thickness of the wall; (4) a shear stress s_s, assumed uniform throughout the thickness of the wall.

In a thick walled vessel (thickness more than one-tenth the radius) the meridianal and hoop stresses cannot be considered uniform throughout the thickness of the wall, and the radial stresses cannot be neglected. These stresses in thick vessels, here called *wall stresses*, must be found by formulas quite different from those used in finding the membrane stresses in thin vessels. Discontinuity stresses are produced in thick vessels by the same factors that cause them in thin vessels, and in addition appreciable bending stresses may occur even when there are no discontinuities present.

The formulas given for discontinuity stresses are for the most part taken from the papers by Coates (Ref. 6) and by Maulbetsch and Hetenyi (Ref. 5). *Trans.* Am. Soc. Mechanical Engrs.; (3) the wall stresses and corresponding deformations in thick vessels.

Formulas for Thin Vessels

p = unit pressure (lb. per sq.in.)

s_1 = meridional membrane stress, positive when tensile (lb. per sq.in.)

s_2 = hoop membrane stress, positive when tensile (lb. per sq.in.)

s_1' = meridional bending stress due to discontinuity, positive when tensile on convex face of wall (lb. per sq.in.)

s_2' = hoop bending stress due to discontinuity, positive when tensile on convex face of wall. (lb. per sq.in.)

s_2'' = direct or normal hoop stress due to discontinuity, positive when tensile (lb. per sq.in.)

s_s = shear stress due to discontinuity. (lb. per sq.in.)

V_o, V_x = transverse shear normal to wall, positive when acting as shown (lb. per linear in.)

M_o, M_x = bending moment, uniform along circumference, positive when acting as shown. (in. lb. per linear in.)

x = distance measured along meridian from edge of vessel or from discontinuity (in.)

R_1 = radius of curvature of wall along meridian. (in.)

R_2 = radius of curvature of wall normal to meridian. (in.)

R = radius of circumference. (in.)

(R_1 R_2 and R are mean radii.)

t = wall thickness (in.)

E = modulus of elasticity (lb. per sq. in.)

ν = Poisson's ratio

$$D = \frac{Et^3}{12(1-\nu^2)}$$

$$\lambda = \sqrt[4]{\frac{3(1-\nu^2)}{R_2{}^2 t}}$$

Radial displacement = radial deflection of wall relative to the axis of vessel, positive when outward (in.)

θ = change in slope of wall, positive when outward. (radians)

Subscripts 1 and 2 refer to the parts into which the vessel is imagined as divided, e.g., cylindrical shell and hemispherical head.

All formulas for thin vessels are for internal pressure; they may be used to find stresses caused by external pressure by giving p a negative sign. The stresses so found, however, are significant only when the pressure is insufficient to cause failure through *elastic instability*. This type of failure is not considered here; formulas for the crit-

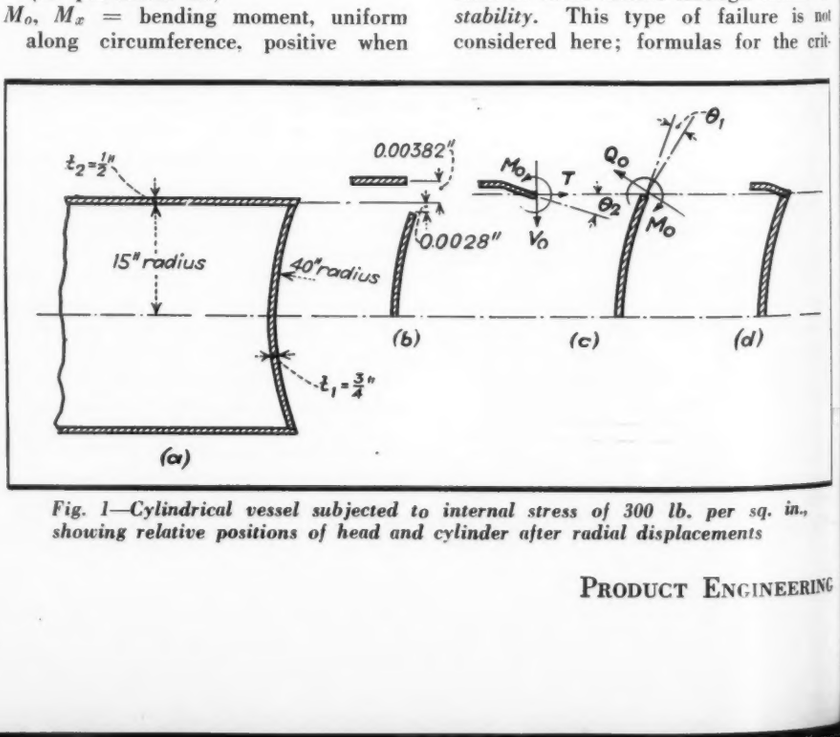


Fig. 1—Cylindrical vessel subjected to internal stress of 300 lb. per sq. in., showing relative positions of head and cylinder after radial displacements

ical pressure producing elastic instability will be found in References 7 and 8.

Formulas for Thick Vessels

The notation used in the formulas for thick vessels is as follows:

s_1 = meridional wall stress, positive when acting as shown (lb. per sq.in.)
s_2 = hoop wall stress, positive when acting as shown (lb. per sq.in.)
s_3 = radial wall stress, positive when acting as shown (lb. per sq.in.)
a = inner radius of vessel (in.)
b = outer radius of vessel (in.)
r = distance from axis of vessel to point where stress is to be found (in.)
Δa = change in inner radius due to pressure, positive when it represents an increase (in)
Δb = change in outer radius due to pressure, positive when it represents an increase (in.)

In other respects the notation is the same as that used for thin vessels.

Example I

The vessel shown in longitudinal section in Fig. 1a consists of a cylindrical shell ½ in. thick and 30 in. in diameter with inverted spherical heads ¾ in. thick and of 40 in. radius. This vessel is subjected to an internal pressure of 300 lb. per sq. in. It is required to determine the stresses at the junction of head and cylinder in each part. The vessel described is not chosen as an example of good design, but as affording a case of discontinuity presenting most of the difficulties likely to be encountered, i.e., change in thickness, slope and curvature.

Solution: Designating by the subscript 1 properties pertaining to the head, and by the subscript 2 those pertaining to the cylinder, and taking $E = 30.000.000$ and $\nu = 0.3$, we have:

$\lambda_1 = 0.2345$; $\lambda_2 = 0.469$; $D_1 = 1,160,000$; $D_2 = 343,500$; $\phi_1 = 22°$; $\sin \phi_1 = 0.375$; $\cot \phi_1 = 2.475$; $\phi_2 = 90°$; $\sin \phi_2 = 1$; $\cot \phi_2 = 0$

Solving now for the membrane stresses and radial displacement in each part as though the discontinuity (joint) were not present, we have:

For the head (Case 2) $s_1 = -8000$
$s_2 = -8000$
Radial displacement = −0.0028 in.
For the cylinder (Case 1) $s_1 = +4500$
$s_2 = +9000$
Radial displacement = +0.00382 in.

Fig. 1*b* shows the relative positions of head and cylinder after the radial displacements have occurred. The separation of the parts here pictured is prevented by the edge moments M_o and edge shears V_o and Q_o, which may be imagined to act after the separation and to force the edges together as shown in Fig. 1 *c* and *d*. The moments M_o are obviously equal; the shears V_o and Q_o are not equal, but Q_o can be found in terms of V_o by noting that the meridional tension T at the edge of the cylinder is equal to $(ts_1) = 2250$ lb. per linear in., and that Q_o is therefore equal to: $V_o \sin \phi_1 + 2250 \cos \phi_1 = 0.375\, V_o + 2085$.

The values of V_o and M_o are now found from the two following conditions:

(1) The outward displacement of the head plus the inward displacement of the cylinder must equal the algebraic difference in their original unrestrained radial displacements, or 0.00662 in.

(2) The change in edge slope of the head must equal the change in edge slope of the cylinder, i.e., $\theta_1 = \theta_2$

(It is here assumed that these displacements are due wholly to the moments M_o and the shears V_o and Q_o; the effect of the increment in meridianal stress in the head due to V_o and T is considered negligible).

Expressing the above conditions (1) and (2) by the appropriate formulas for Cases 10, 11, 12 and 13, and paying particular attention to the signs of the several quantities, we have:

$$(1)\quad -\frac{M_o}{2\,D_1\,\lambda_1^2}\sin\phi_1 + \left(\frac{0.375\,V_o + 2085}{2\,D_1}\right)\sin^2\phi_1\left(\frac{1}{\lambda_1^3} - \frac{1}{\lambda_1^4}\,\frac{\nu}{2R_2}\cot\phi_1\right) + \frac{V_o}{2\,D_2\,\lambda_2^3} - \frac{M_0}{2\,D_2\,\lambda_2^2} = 0.00662$$

$$(2)\quad \frac{M_o}{\lambda_1\,D_1} - \frac{0.375\,V_o + 2085}{2\,\lambda_1^2\,D_1}\sin\phi_1 = -\frac{M_o}{\lambda_2\,D_2} + \frac{V_o}{2D_2\,\lambda_2^2}$$

Substituting the numerical values of D_1, D_2, λ_1, λ_2, $\sin \phi_1$, $\cot \phi_1$ collecting terms, and solving the equations simultaneously for M_o and V_o, we find $M_o = 495$ in. lb. per in.; $V_o = 118$ lb. per in.; $Q_o = 2130$ lb. per in.

For the head:

$s_1' = 5280$ lb. per sq.in., tensile on convex side.
$s_2' = 13100$ lb. per sq.in., tensile on convex side.
$s_2'' = 7100$ lb. per sq.in., tensile
$s_3 = 2840$ lb. per sq.in.

For the cylinder:

$s_1' = 11900$ lb. per sq.in., tensile on inner face
$s_2' = 3570$ lb. per sq.in., tensile on inner face
$s_2'' = 3320$ lb. per sq.in., compressive
$s_3 = 236$ lb. per sq.in.

To find the maximum stresses, the membrane stresses must be superposed upon these discontinuity stresses, giving the following results:

Maximum meridional stress = −8000 − 5280 = −13280 lb. per sq. in. (compressive stress on concave face)

Maximum hoop stress = −8000 + 7100 + 13100 = +12200 lb. per sq.in. (tensile stress on convex face) and
−8000 + 7100 − 13100 = −14000 lb. per sq.in. (compressive stress on concave face)

Maximum meridional stress = +11900 + 4500 = +16400 lb. per sq.in.

Maximum hoop stress = +3570 − 3320 + 9000 = 9250 lb. per sq.in.

Since the discontinuity stresses fade out rapidly and become very small at even a short distance from the discontinuity, the above stresses are probably the maximum nominal stresses that occur.

No account, however, was taken in the above calculations of the stress concentration due to the sharp re-entrant angle between cylinder and head, which would increase the meridional stresses at that point. Under conditions of essentially steady loading, this stress concentration could be safely ignored, but if the pressure fluctuated repeatedly between wide limits, the fatigue effect might lead to failure. By adopting a radically different design, with an elliptical or approximately elliptical head having the same thickness as the shell, tangent thereto, and convex outward instead of inward, the discontinuity stresses could be greatly reduced and stress concentration eliminated. In the API-ASME code for unfired pressure vessels (Ref. 9) discontinuity stresses of the junction of shell and head are not taken into account, the requisite thickness being calculated on the basis of the membrane stresses only.

Example II

At the powder chamber, the inner radius of a 3 in. gun tube is 1.605 in.; the outer radius is 2.425 in. It is desired to shrink a jacket on this tube so as to produce a radial pressure between tube and jacket of 7600 lb. per sq.in. The outer radius of this jacket is 3.850 in. It is required to determine the difference between the inner radius of the jacket and the outer radius of the tube in order to produce the desired pressure, to calculate the stresses in each part when assembled, and to calculate the stresses in each part when the gun is fired, generating a powder pressure of 32000 lb. per sq.in.

Solution: Using the formulas for Case 16, it is found that for an external pressure of 7600 the stress s_2 at the outer surface of the tube is −19430, the stress s_2 at the inner surface is −27050, and the change in outer radius $\Delta b = -0.001385$ in. It is found that for an internal pressure of 7600 the stress s_2 at the inner surface of the jacket is +17630, the stress s_2 at the outer surface is +13170, and the change in inner radius $\Delta a = +0.001615$ in. In making these calculations the inner radius of the jacket is assumed to be 2.425 in. The initial difference between the inner

radius of the jacket and outer radius of the tube must be equal to the sum of the radial deformations they suffer, or 0.001385 + 0.001615 = 0.0030 in. Therefore the initial inner radius of the jacket should be 2.425 — 0.0030 = 2.422 in.

The stresses produced by the powder pressure are calculated at the inner surface of the tube. at the common surface of the tube and jacket (r = 2.425) and at the outer surface of the jacket.

For the tube: (at inner surface)

$$s_2 = +32000\left(\frac{3.85^2 + 1.605^2}{3.85^2 - 1.605^2}\right) = +45450 \text{ (tensile)}$$

$$s_3 = +32000$$

For tube and jacket: (at common surface)

$$s_2 = +32000\left(\frac{1.605^2}{2.425^2}\right)$$

$$\left(\frac{3.85^2 + 2.425^2}{3.85^2 - 1.605^2}\right) = +23{,}500 \text{ (tensile)}$$

$$s_3 = +32000\left(\frac{1.605}{2.425^2}\right)$$

$$\left(\frac{3.85^2 - 2.425^2}{3.85^2 - 1.605^2}\right) = +10{,}200 \text{ (compressive)}$$

For jacket: (at outer surface)

$$s_2 = +32000\left(\frac{1.605^2}{3.85^2}\right)$$

$$\left(\frac{3.85^2 + 3.85^2}{3.85^2 - 1.605^2}\right) = +13{,}500 \text{ tensile}$$

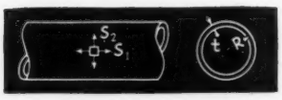
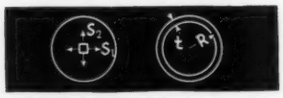
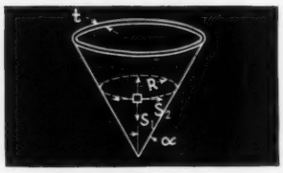
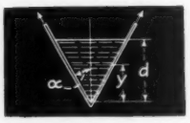
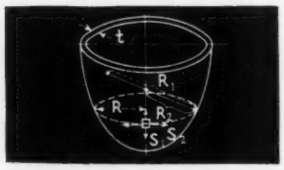
These are the stresses due to the powder pressure. Superposing the stresses due to the shrinkage, we have as the resultant stresses:

At inner surface of tube,
$s_2 = -27050 + 45450 = +8400$ lb. per sq.in. (tensile)
$s_3 = 0 + 32000 = +32000$ lb. per sq.in. (compressive)

At outer surface of tube,
$s_2 = -19430 + 23500 = +4070$ lb. per sq.in. (tensile)
$s_3 = +7600 + 10200 = +17800$ lb. per sq.in. (compressive)

At inner surface of jacket,
$s_2 = +17630 + 23500 = +41130$ lb. per sq.in. (tensile)
$s_3 = +7600 + 10200 = +17800$ lb. per sq.in. (compressive)

At outer surface of jacket,
$s_2 = +13170 + 13500 = +26670$ lb. per sq.in. (tensile)
$s_3 = 0$

FORM OF VESSEL	MANNER OF LOADING	THIN VESSELS — MEMBRANE STRESSES
 CYLINDRICAL	**1.** Uniform internal (or external) pressure p lb. per cu. in.	$s_1 = pR/2t$ $s_2 = pR/t$ Radial displacement $= R/E\,(s_2 - \nu s_1)$. Collapsing pressure $p' = \frac{t}{R}\left(\frac{s_y}{1 + 4\,\frac{s_y}{E}\left(\frac{R}{t}\right)^2}\right)$ where s_y = compressive yield point of material (Ref. 1). This formula is for *non-elastic* failure, and holds only when $\frac{p'R}{t} >$ proportional limit. For critical stress producing *elastic* instability in very thin cylinder, see Ref. 7 **(Ref. 1, 8).**
 SPHERICAL	**2.** Uniform internal (or external) pressure p lb. per cu. in.	$s_1 = s_2 = pR/2t$ Radial displacement $= \frac{Rs}{E}(1 - \nu)$
 CONICAL	**3.** Uniform internal (or external) pressure p lb. per cu. in.	$s_1 = pR/2t\cos\alpha$ $s_2 = pR/t\cos\alpha$
	 **4.** Filled to depth d with liquid of sp. wt. σ lb. per cu. in.	At any level y above bottom. $s_1 = \frac{\sigma\, y \tan\alpha}{2t\cos\alpha}\left(d - 2/3y\right)$, Max. $s_1 = \frac{3\,\sigma\, d^2 \tan\alpha}{16t\cos\alpha}$ when $y = 3/4\,d$ $s_2 = \frac{(d - y)\,\sigma\, y \tan\alpha}{t\cos\alpha}$, Max. $s_2 = \frac{\sigma\, d^2 \tan\alpha}{4t\cos\alpha}$ when $y = 1/2\,d$
 ANY FIGURE OF REVOLUTION	**5.** Uniform internal (or external) pressure p lb. per sq. in.	$s_1 = pR_2/2\,t$ $s_2 = pR_2/2\,t\left(2 - \frac{R_2}{R_1}\right)$ Radial displacement $= R/E\,(s_2 - \nu s_1)$